Research Issues in Wireless Sensor Network Applications: A Survey

Edwin Prem Kumar Gilbert, Baskaran Kaliaperumal, and Elijah Blessing Rajsingh

***Abstract*—Wireless Sensor Networks (WSN) are used in variety of fields which includes military, healthcare, environmental, biological, home and other commercial applications. With the huge advancement in the field of embedded computer and sensor technology, Wireless Sensor Networks (WSN), which is composed of several thousands of sensor nodes which are capable of sensing, actuating, and relaying the collected information, have made remarkable impact everywhere. This paper presents an overview of the various research issues in WSN based applications.**

***Index Terms*—Wireless sensor network, task mapping, Smart parking, event detection, SHM, greenhouse monitoring, health care, C4ISRT.**

I. Introduction

Innovations in industrial, home and automation in transportation represent smart environments. Data for smart environments are obtained through Wireless Sensor Networks (WSN), where thousands of sensors are deployed at different locations operating in different modes [1]. A sensor network is capable of sensing, processing and communicating which helps the base station or command node to observe and react according to the condition in a particular environment (physical, battle field, biological) [2].

Sensor network protocols have a unique self-organizing capability. Another interesting feature of WSNs is that the sensor nodes cooperate with each other. Sensor nodes have an in-built processor, using which raw data are processed before transmission. These features facilitate wide range of applications of WSNs ranging from biomedical, environmental, military, event detection and vehicular telematics [3]. This paper presents a detailed overview of the research issues in the applications of Wireless Sensor Networks. Fig.1 depicts the overview of WSN applications.

II. Research Issues in Biological Applications

The WSN based applications have made tremendous impact for biological problems. Some of these include biological task mapping and scheduling, biomedical signal monitoring etc. A brief description of these applications has been presented in this section

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A. Biological Task Mapping

WSNs find widespread applications in the area of biological sensing. Specifically, there is recent research going on in the concept of "labs on a chip", supported by latest technologies like nano-techniques. The use of WSNs for biological applications have been accelerated due to the advancements in Micro Electro-Mechanical Systems (MEMS), embedded systems, microcontrollers and various wireless communication technologies.

Y.E.M. Hamouda and C. Phillips [4] presented a BTMS (Biological Task Mapping and Scheduling) algorithm, in which a group of nodes was used to execute an application. In this work, it was assumed that the application could be broken down into smaller tasks with different weights and hence a general model was considered for complex applications. In order to achieve and enhance the desired performance objectives, assigning of resources to tasks is known as Task mapping and the sequence of execution of the tasks is known as task scheduling. Task mapping and scheduling are of much importance in high performance computing. A near-optimal solution for task mapping can be obtained using heuristic techniques. But the constrained resources of WSNs require the design objectives to be different. However the simulation model that was built was applicable only if the nodes in the WSN were separated with a distance set to 150m.

B. Biomedical Signal Monitoring

WSNs have revolutionized the field of medicine in many ways. Telemedicine is the field which involves the treatment and care of patients from a distance and also aids in biomedical diagnosis. The application of WSNs has significantly improved this field.

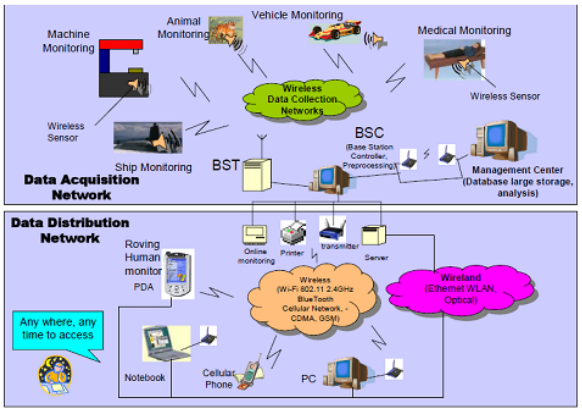


Fig. 1. Overview of WSN applications

The basic principles and features required at the time of development of a functional model for the monitoring of

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biological signals have been presented in [5]. To develop modern equipments for monitoring patients in remote places using wireless technologies, the network topology, sensors specific signal reception and analysis has been considered.

III. Research Issues in Commercial Applications

Some of the commercial applications of WSNs include vehicular monitoring, cultural property protection, event detection and structural health monitoring. These applications have a profound impact on ordinary day-to-day affairs.

A. Smart Parking

WSNs are widely used in the applications like intelligent parking for the purposes such as effective usage of existing parking lots instead of making expensive investments in new installations and to make provisions for coupling with cheap sensor nodes which can track the vehicles effectively. Existing solution for parking application uses magnetometers and video cameras. The detections of magnetometers are not very accurate as they are influenced by environmental factors. Video camera which is the alternate is expensive and it is not feasible to transmit large amount of data in a wireless environment through multiple hops. Another factor which affects the application of magnetometers and video cameras is that in a parking lot, apart from entry and exit of vehicles there may be other moving objects, which is a great challenge.

Detection of vehicles in a parking lot using magnetic sensors along with ultrasonic sensors together has been presented by S.Lee, D.Yoon and A. Ghosh in [6]. It was proved that accurate vehicular detection was possible with the combined use of ultrasonic sensors and magnetometers but it did not provide any solution for better parking management.

A WSN based Smart PARKing (SPARK) management system has been presented in [7]. Monitoring of remote parking, mechanism for parking reservation and automated guidance are some of the latest features provided by the system. However, the system should be made fault tolerant, by incorporating mechanisms for identifying defaulters.

B. Vehicular Telematics

A detailed overview of vehicular telematics over heterogeneous wireless sensor networks has been presented in [8]. In this work, an advanced architecture that collaboratively uses multiple radios and access technologies, known as Advance Heterogeneous Vehicular Network (AHVN) architecture has been discussed. Sufficient light has been thrown on the various challenges and factors involved in the development of the functional components of AHVN and its related protocols. These included radio link control and congestion control, routing, security and other application development. In order to realize AHVN architecture for vehicular telematics over heterogeneous wireless networks the research issues to be explored include enhanced multi-channel MAC protocols for Dedicated Short Range Communications(DSRC), dynamic spectrum sharing between DSRC and WiMAX, Heterogeneous wireless access for vehicular telematics, multimedia transmission and Qos support and data congestion in vehicular telematics.

C. Security of Intra-Car

Fuel efficiency and reduction in the weight of automotives can be achieved by replacing wired sensors and their cables with wireless sensors. However, the inherent vulnerability of the wireless platform makes the security issues of such a replacement, highly questionable. Security problems for intra-car wireless sensor networks have been addressed in [9]. In this work, selection of appropriate security algorithms for WSNs using a systematic methodology and determination of the best combination with regard to execution time and security has been presented.

D. Event Detection

Tracking is a typical characteristic of wireless sensor networks, especially for instant tracking of events. Much work has been done in WSN, with sensor nodes having identical sensing units. However, the utilization of different types of sensor nodes is an area yet to be explored. A fully distributed protocol Collaborative Event Detection and Tracking (CollECT), for event detection and tracking in wireless heterogeneous sensor networks has been presented in [10]. However, solutions to sensor node deployment, data dissemination and routing in Wireless Heterogeneous Sensor Networks (WHSNs) are the issues yet to be addressed.

E. Structural Health Monitoring

The process of detection of damage for civil, aerospace and other engineering systems is referred to as Structural Health Monitoring (SHM). Any change in the material or geometric properties of these systems due to internal factors (aging) or external factors (natural calamities, pollution) is termed as damage. The normal operation of an SHM system includes low power, long-term monitoring of a structure to provide periodic updation of its health condition. However, during critical events such as earthquakes and other natural disasters, real-time rapid structural conditional screening can be done using SHM system. A WSN based application for long-term, online SHM based information processing approach is presented in [11].

A novel WSN based application for SHM is presented in [12]. In order to do away with the limitations of traditional sensing networks, both the power and data interrogation commands are transmitted through a mobile agent, which is sent to each sensor node to perform individual functions. Prototype systems used to interrogate capacitive-based and impedance-based sensors for SHM applications have been discussed in this paper. The construction of WSN platform with vibration sensing and Global Positioning System (GPS) positioning for SHM application has been presented in [13].

The challenges involved in WSN based application for SHM include rigid bandwidth requirements, extended network lifetime and limiting multi-hop data exchange.

IV. Research Issues in Environmental Applications

Environmental applications include the monitoring of

atmospheric parameters, tracking of the movements of birds and animals, forest fire detection, habitat surveillance etc.

A. Greenhouse Monitoring

To ensure that the automation system in a greenhouse works properly, it is necessary to measure the local climate parameters at various points of observation in different parts of the big greenhouse. This work if done using a wired network will make the entire system clumsy and costly. However, a WSN based application for the same purpose using several small size sensor nodes equipped with radio would be a cost effective solution. Such an application has been developed in [14]. Data analysis, DSP based control solutions and more complex network setups are the areas yet to be explored.

B. Habitat Surveillance

WSNs find widespread application in habitat surveillance compared to other monitoring methods due to high deployment density and self-organisation of the sensor nodes. The advantage with WSN is that the invisible placement of sensor nodes in the habitat does not leave any noticeable mark which might affect the behaviour pattern of the inhabitants. A WSN based application in combination with General Packet Radio Service (GPRS) for habitat monitoring is introduced in [15]. The details of a sensor node that made use of the combination of ARM technology and IEEE 502.15.4 has been given. This paper addressed the energy management issue and developed a low-weight, constant duty cycle policy for energy management. However, developing a WSN based application that will never affect the biological behaviour of the inhabitant species is very important, and hence a challenge to be considered.

V. Research Issues in Healthcare Applications

WSNs are very efficient in supporting various day-to-day applications. WSN based technologies have revolutionized home and elderly healthcare applications. Physiological parameters of patients can be monitored remotely by physicians and caretakers without affecting the patients' activities. This has resulted in reduction of costs, improvement of equipments and better management of patients reaping huge commercial benefits. These technologies have significantly minimised human errors, allowed better understanding into origin of diseases and has helped in devising methods for rehabilitation, recovery and the impacts of drug therapy. The recent developments in the application of WSN in healthcare are being presented. The implementation and analysis of a WSN based e-Health application has been described in [16]. The main research issue to be addressed is to increase the degree of awareness of home assistants, caregivers, primary healthcare centers, to understand the patients' health and activity status to quickly discern and decide on the required action. A simple localisation algorithm based on sensor data and Received Signal Strength Indicator (RSSI) was presented. This algorithm was proved experimentally to work fine in home environment. However, the use of multi-sensor analysis, which is expected to give better accuracy, is an area yet to be explored.

A qualitative research on the perceptions and acceptance of elderly persons regarding the usage of WSN for assisting their healthcare is done in [17]. A light-weight, low-cost WSN based home healthcare monitor has been developed in [18]. An attempt to integrate the WSN technology and public communication networks in order to develop a healthcare system for elderly people at home without disturbing their routine activities has been presented in [19]. Improved performance with minimum decision delay and good accuracy using Hidden Markov Model is yet to be addressed.

A WSN based home healthcare application is developed in [20]. The main issue that was considered in this research is the development of a working model of home healthcare monitoring system with efficient power, reliability and bandwidth. A WSN based prototype sensor network for monitoring of health, with sensors for heart activity, using 802.15.4 complaint network nodes is described in [21]. The issues regarding its implementation have also been discussed. The paper also describes the hardware and software organisation of the presented system and provides solutions for synchronisation of time, management of power and on-chip signal processing. However, the areas that are yet to be addressed are improvement in QoS of wireless communication, standardization of interfaces and interoperability. Specific limitations and new applications of the technology can be determined by in-depth study of different medical conditions in clinical and ambulatory settings.

Reference [22] presents the micro Subscription Management System (μSMS) middleware, using an event-based service model. This novel approach meets the design constraints of limited resources, efficiency, scalability, dependability and low power consumption by implementing a dynamic memory kernel and a mechanism of variable payload multiplexing for the information events to provide better services. It was observed that application of this approach yielded best results for e-health applications.

For continuous and real-time monitoring of health Y.D. Lee and W. Y. Chung developed a smart shirt which measured ECG (Electro Cardio Gram) and acceleration signals [23]. The shirt was made up of conductive fabrics to obtain the body signal as electrodes and consisted of sensors for online health data monitoring. The observed and measured data are transmitted in an ad-hoc network for remote monitoring.

VI. Research Issues in Industrial Applications

Nowadays, industrial applications are built on distributed architectures and they are required to be inexpensive, flexible and dependable. The system's performance can be improved by interfacing sensors and actuators directly to the industrial communication network, as data and diagnostics can be made accessible to many systems and also shared on the web. A detailed survey on the latest developments in WSN based industrial applications is presented in [24]. The WSN based industrial applications are shown in Fig. 2.

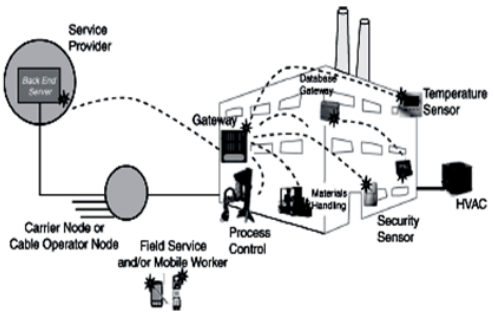


Fig. 2. Industrial applications

The applications of WSN in petrochemical industry based on ZigBee technology has been discussed in [25]. The application of WSN for safety monitoring of coal mines has been described in [26]. Development of anti-interference and explosion-proof hardware is the focus of further research.

A WSN based remote online Automatic Meter Reading (AMR) system is presented in [27]. Latest technologies like wireless RF, ZigBee modules and Code Division Multiple Access (CDMA) telecommunication are used in the remote metering technology. Direct access or physical reading of meters, in order to transmit the usage of parameters like electricity, gas, water etc. is not possible always. Hence, the solutions provided by WSN based remote meters have remarkably changed the way companies, organisations and individuals monitor water, gas and other resources.

WSN based real-time and distant energy monitoring and fault diagnosis in industrial motor system has been presented in [28]. Here the electrical signal based motor signature analysis has been integrated with WSNs for best results. Sensor fusion of various sensor measurements, a comprehensive performance analysis of WSNs in industrial environments, evaluation of the effect of the network-error-control mechanisms are the areas yet to be explored. A WSN based approach is developed for detection of faults in metal cutting process in [29]. The machine tools can be maintained in good condition and the occurrence of wearing of tool can be delayed by using appropriate monitoring systems. The mathematical model of the novel distributed WSN based method is described in detail in [29] and experimental results were included that prove its effectiveness.

A WSN based digital system for evaluation of energy usage, condition monitoring, diagnosis and supervisory control for electric systems with Dynamic Power Management (DPM) have been presented in [30]. Two hardware topologies used for signal acquisition, processing and transmission form the basis of this system. They are ISMs (Intelligent Sensor Modules) and RDAUs (Remote Data Acquisition Units). A Dynamic Power Management Protocol is implemented by sensor nodes, to extend the WSN lifetime.

A WSN based security system for a power plant using human motion sensor has been presented in [31]. Detection of trespassers and sending notification to administrator is the important function of the system. A WSN based system for measuring and monitoring water quality is presented in [32]. Design of complex underwater acoustic sensor networks that can be used in deep waters is an area yet to be addressed.

VII. Research Issues in Military Applications

WSNs play a vital role in military Command, Control, Communications, Computing, Intelligence, Surveillance, Reconnaissance and Targeting (C4ISRT) systems.

Few challenges faced by WSNs on the battlefield are addressed in [33]. In the battlefield, the WSNs are prone to the attacks, where either the data or corrupting control devices are attacked, leading to large amount of energy consumption and finally to the exit of nodes from work. The energy efficiency of sensor nodes and the correct modelling of energy consumption are the research issues yet to be explored.

WSN based collaborative target detection with reactive mobility has been presented in [34]. A sensor movement scheduling algorithm was developed and its effectiveness was proved using extensive simulations. WSNs have found application in very critical applications such as object detection and tracking. These applications require high detection probability, low false alarm rate and bounded detection delay.

VIII. Conclusion

An overview of the broad spectrum of applications of WSN has been given in this paper. The application of WSN in the areas of biomedical, intelligent parking, healthcare applications, environmental, industrial, and military applications have been briefed. These interesting applications are possible due to the flexibility, fault tolerance, low cost and rapid deployment characteristics of sensor networks. Though wireless sensor networks are constrained by scalability, cost, topology change and power consumption, new technologies are being devised to overcome these and to make sensor networks an integral part of our lives. A review on the various research issues involved in the WSN applications has been outlined. Research on these issues will lead to promising results, making WSN based applications very popular. The application of WSNs is not limited to the areas mentioned in this paper. The future prospects of WSN applications are highly promising to revolutionize our everyday lives.

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