INTERNATIONAL JOURNAL OF APPLIED ENGINEERING RESEARCH, DINDIGUL
Volume 1, No 3, 2010

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REVIEW ARTICLE ISSN - 0976-4259

Recent advances and future trends in Wireless Sensor Networks

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ABSTRACT

Wireless Sensor networks (WSNs) have become one of the most interesting areas of research in the past few years. A WSN is composed of a number of wireless sensor nodes which form a sensor field and a sink. These large numbers of nodes, having the abilities to sense their surroundings, perform limited computation and communicate wirelessly form the WSNs. Recent advances in wireless and electronic technologies have enabled a wide range of applications of WSNs in military, traffic surveillance, target tracking, environment monitoring, healthcare monitoring, and so on. There are many new challenges that have surfaced for the designers of WSNs, in order to meet the requirements of various applications like sensed quantities, size of nodes, and nodes' autonomy. Therefore, improvements in the current technologies and better solutions to these challenges are required. The future developments in sensor nodes must produce very powerful and cost-effective devices, so that they may be used in applications like underwater acoustic sensor systems, sensing based cyber-physical systems, time-critical applications, cognitive sensing and spectrum management, and security and privacy management. This paper also describes the research challenges for WSNs.

Key words: Future trends, recent advances, research challenges, wireless sensor networks

1. Introduction

With the advances in the technology of micro-electromechanical system (MEMS), developments in wireless communications and WSNs have also emerged. WSNs have become the one of the most interesting areas of research in the past few years. Here, we look into the recent advances and future trends in WSNs.

WSNs are usually composed of small, low-cost devices that communicate wirelessly and have the capabilities of processing, sensing and storing. The development of WSNs was motivated by military applications such as battlefield surveillance. WSN are being used in many industrial and civilian application areas, including industrial process monitoring and control described by Kay and Mattern (2004), machine health monitoring described by Tiwari (2007), environment and habitat monitoring, healthcare applications, home automation, and traffic control presented well by Kay & Mattern (2004) and Hadim (2006).

A WSN generally consists of a base-station (also called as gateway sometimes) that can communicate with a number of wireless sensors via a radio link. Wireless sensor nodes collect the data, compress it, and transmit it to the gateway directly or indirectly with the help of other nodes. The transmitted data is then presented to the system by the gateway connection. This paper discusses the recent advances in WSNs that enable a wide range of applications and future

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REVIEW ARTICLE ISSN - 0976-4259

development in applications like underwater acoustic sensor systems; sensing based cyber-physical systems, time-critical applications, cognitive sensing and spectrum management, and security and privacy management. Rest of the paper is organized as follows. Section 2 describes the recent advances in WSNs. We discuss future trends in WSN in Section 3. Section 4 describes the research challenges for WSN. Finally Section 5 presents the conclusion.

2. Recent Advances

Recent advances in wireless and electronic technologies have enabled a wide range of applications of WSNs in military sensing, traffic surveillance, target tracking, environment monitoring, healthcare monitoring, and so on. Here we describe such type advances in WSN and their applications in various fields.

1.1. Sensor Localization and Location-Aware Services

1.1.1. Smart Home/Smart Office

Smart home environments can provide custom behaviors for a given individual. Considerable amount of research has been devoted to this topic. The research on smart homes is now starting to make its way into the market. It takes a considerable amount of work and planning to create a smart home. There are many examples of products currently on the market which can perform individual functions that are considered to be part of a smart home. Several useful applications which take advantage of information collected by WSN are presented by Hussain *et al.* (2009).

1.1.2. Military

New and emerging technologies, such as networks, support military operations by delivering critical information rapidly and dependably to the right individual or organization at the right time. This improves the efficiency of combat operations. The new technologies must be integrated quickly into a comprehensive architecture to meet the requirements of present time. Improvement in situation awareness (Chien-Chung Shen, 2001) is must requirement. Doumit and Agrawal (2002) described some other important application is detection of enemy units' movements on land/sea, sensing intruders on bases, chemical/biological threats and offering logistics in urban warfare. Command, control, communications, computing, intelligence, surveillance, reconnaissance, and targeting systems are well described by Akyildiz (2002).

1.1.3. Industrial & Commercial

Since the long time wireless transmission of data is being done in industrial applications, but recently it has gained importance. Successful use of wireless sensors in systems such as supervisory control and data acquisition has proved that these devices could effectively address the needs of industrial applications. The critical process applications of WSNs in industry are monitoring temperature, flow-level, and pressure parameters.

INTERNATIONAL JOURNAL OF APPLIED ENGINEERING RESEARCH, DINDIGUL
Volume 1, No 3, 2010

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REVIEW ARTICLE ISSN - 0976-4259

With the rapidly increasing technological advances in wireless technology and its subsequently decreasing prices, numerous wireless applications are being developed in industry. WSN in manufacturing industries can monitor and optimize quality control.

1.1.4. Traffic Management and Monitoring

Every big city is suffering from traffic congestion around the world. A sincere effort is being made to solve the traffic congestion. Congestion can be alleviated by planning managing traffic. A real-time automatic traffic data collection must be employed for efficient management of rush-hour traffic. Research on this topic is considered as part of the Intelligent Transport System (ITS) research community. Chinrungrueng (2006) explained ITS to be the application of the computers, communications, and sensor technology to surface transportation.

The vehicle tracking application is to locate a specific vehicle or moving object and monitor its movement. This work also describes design of WSN for vehicular monitoring. As the power source (battery) is limited, it is important that a design of sensor node is power efficient.

1.1.5. Structural Healthcare

Structures are inspected at regular time intervals, and repairing or replacing based on the time of use, rather than on their working conditions. Tiwari *et al.* (2004) has explained that sensors embedded into structures enable condition-based maintenance of these assets. Wireless sensing will allow assets to be inspected when the sensors indicate that there may be a problem. This will reduce the cost of maintenance and preventing harmful failure. These applications include sensors mounted on heavy duty bridges, within concrete and composite materials (Arms *et al.* 2001), and big buildings.

1.1.6. Agriculture

Wang and Wang (2006) stated that agriculture can also be benefited by the deployment of WSN to get the information regarding soil degradation and water scarcity. With help of WSNs we can check the clean water consumed in irrigation and manage it.

1.2. Topology and Coverage Control

Topology control is one of the fundamental problems in WSNs. It has great importance for prolong lifetime, reducing radio interference, increasing the efficiency of media access control protocols and routing protocols. It also ensures the quality of connectivity & coverage and increase in the network service as well. A significant progress in research can be seen in WSNs topology control. Many topology control algorithms have been developed till date, but problems such as lack of definite and practical algorithm, lack of efficient measurement of network performance and idealness of mathematical model still exist. Several graph models used in topology control, the present hot spots and the future trends on the research of topology control are presented by Jardosh and Ranjan (2008).

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1.3. Quality of Service (QoS) Provision

QoS support is challenging due to severe energy and computational resource constrains of wireless sensors. Various service properties such as the delay, reliability, network lifetime, and quality of data may conflict; for example, multi-path routing can improve the reliability; however it can increase the energy consumption and delay due to duplicate transmissions. Modeling such relationships, measuring the provided quality, and providing means to control the balance is essential for QoS support.

There are various research opportunities in enhancing the QoS of WSNs. One of the researches is the project described by Abidin (2009) that analyzes and enhances the performance of a WSN by deploying a simple max-min fairness bandwidth allocation technique.

1.4. Mobility management

Mobility is one of the most important issues in next generation networks. As WSNs are becoming the next elements of the future Internet, it is crucial to study new models that also support mobility of these nodes. WSNs are applicable in variety of cases that make it difficult to produce a standard mobility scenario. Following are some cases where the mobile support is necessary presented in Camilo (2008).

Intra-WSN device movement is probably the most common scenario in WSNs architectures, where each sensor node has the ability to change from its local position at run time without losing the connectivity with the sensor router (SR). In the case of inter-WSN device movement, sensor nodes move between different sensor networks, each one with its SR responsible to configure and manage all the aggregated devices.

A research project of IETF working group NEMO, an example of WSN movement is described in RFC-3963 by Devarapalli (2005). Sensor network deployed in a moving bus is a real scenario of this type. It is possible to have a scenario where a sensor network can use another sensor network in order to be connected through Internet. MANEMO (Wakikawa *et al.,* 2007) project is also an example.

1.5. Security and Privacy Concern

The field that paid less attention is the privacy concern on information being collected, transmitted, and analyzed in a WSN. Such private information of concern may include payload data collected by sensors and transmitted through the network to a centralized data processing server. The location of a sensor initiating data communication, and other such context information, may also be the focus of privacy concerns.

In real world applications of WSNs, effective countermeasures against the disclosure of both data and context-oriented private information are indispensable prerequisites. Privacy protection in various fields related to WSNs, such as wired and wireless networking, databases and data

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REVIEW ARTICLE ISSN - 0976-4259

mining, has been extensively studied by Li and Das (2009). Effective privacy-preserving techniques are needed for the unique challenges of WSN security.

1.6. Biomedical/Medical

The uses of WSNs in biomedical and medical are in growing phase. Biomedical wireless sensor networks (BWSNs) show the future opportunities for supporting mobility while monitoring vital body functions in hospital and home care. There is a requirement for BWSN to develop in order to cover security handling, improved signal integration and visualization. They can also be used to achieve extended mobility outside the surgery room, monitoring of several patients/persons at the same time, and further adaptations to medical experts needs for information.

As the Internet usage has become popular among people, e-services for the healthcare which is commonly known as e-Health, have recently attracted significant attention within both the research society and industry. Followings are several ongoing projects for healthcare using WSN:

1. **CodeBlue** (Lorincz *et al.*, 2004) – an architecture proposed for tracking and monitoring of patients.
2. **ALARM-NET** (Wood *et al.*, 2006) – a WSN built for assisted-living and residential monitoring.
3. **AMON** (Anliker *et al.*, 2004) – a Wireless Body Area Sensor Network System
4. **GlucoWatch G2** (Dario *et al.*, 2004) – use WSN to research wearable personal health system that will monitor and evaluate human vital signs.

2. Future Trends

The future developments in sensor nodes must produce very powerful and cost-effective devices, so that they may be used in applications like underwater acoustic sensor systems, sensing based cyber-physical systems, time-critical applications, cognitive sensing and spectrum management, and security and privacy management. In this section we will look into all possibilities of further development in WSN applications.

2.1. Cognitive Sensing

Cognitive sensor networks are used for acquiring localized and situated information of the sensing environment by the deploying a large number of sensors intelligently and autonomically. Managing a large number of wireless sensors is a complex task. As Guang-Zhong Yang (2008) described, a significant research interest can be seen in bio-inspired sensing and networking. Two well known examples of cognitive sensing are swarm intelligence and quorum sensing:

1. Swarm intelligence is developed in artificial intelligence for studying the collective behavior of decentralized, self-organized systems.

2. Quorum sensing is an example of bio-inspired sensing and networking. Quorum sensing is the ability of bacteria to communicate and coordinate behavior via signaling molecules.

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2.2. Spectrum Management

As application of low-power wireless protocols is increasing, we can envision a future in which wireless devices, such as wireless keyboards, power-point presenters, cell phone headsets, and health monitoring sensors will be ubiquitous. But the pervasiveness of these devices leads to increased interference and congestion within as well as between networks, because of overlapping physical frequencies.

Cognitive radios and multi-frequency MACs are some approaches that have been developed to utilize multiple frequencies for parallel communication. A generic solution is provided by Zhou (2009) as SAS: a Self-Adaptive Spectrum Management middleware for WSNs, which can be easily integrated with an existing single frequency.

3.3. Underwater Acoustic Sensor Systems

Akyildiz et al. (2005) presented a complete survey in underwater sensor networks. Underwater sensor networks are designed to enable applications for oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications. Underwater sensors are also being in use for exploration of natural undersea resources and gathering of scientific data. So a need of underwater communications among underwater devices arises. Underwater sensor nodes and vehicles should be capable of coordinate their operation, exchanging their location and movement information and hence relay monitored data to an onshore base-station. A new research paradigm of underwater wireless sensor networks (UWSNs) poses challenges like large propagation delays, node mobility and high error probability of acoustic underwater channels, compared to the ground-based WSNs.

A protocol named DUCS (Distributed Underwater Clustering Scheme) described by Domingo and Prior (2008), is a GPS free routing protocol. It minimizes the proactive routing message exchange and does not use flooding techniques. It also uses data aggregation to eliminate redundant information. Table I shows some of the research projects in UWSNs.

Table 1: Research Projects on UWSNs.

Research lab or project name	URL
BWN-Lab @ GeorgiaTech	http://www.ece.gatech.edu/research/labs/bwn/UWASN/
MIT & Woods Hole O.I.	http://www.mit.edu/people/millitsa/research.html
Sensor Networks for Undersea Seismic Experimentation (SNUSE) @ USC	http://www.isi.edu/ilense/snuse/
Acoustic Research Laboratory (ARL)	http://www.arl.nus.edu.sg/web/research/acomms
Underwater Acoustic Research Group @ Loughborough University	http://sonar-fs.lboro.ac.uk/

3.4. Coordination in Heterogeneous Networks

Since the sensor nodes are energy constraints so the main obstacle in the coordination with other networks is limited energy of sensor nodes. Sensor networks are very useful for applications like

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REVIEW ARTICLE ISSN - 0976-4259

health monitoring, wildlife habitat monitoring, forest fire detection and building controls. To monitor the WSN, the data produced by sensor nodes should be accessible. This can be done by connecting the WSN with existing network infrastructure such as global Internet, a local area network or private internet. Liutkevicius (2010) described two type of interconnection techniques: gateway based interconnection technique and overlay based interconnection technique.

3.5. Time-Critical Applications

A new generation of distributed embedded systems, with a broad range of real-time applications, such as fire monitoring, border surveillance, medical care, and highway traffic coordination, can be represented by WSNs. Due to severe resource limitations in highly dynamic environments these systems face new kinds of timing constraints. Many classical approaches to real-time computing like wireless networking protocols, operating systems, middleware services, data management, programming models, and theoretical analysis are challenged by WSNs.

The design of complex time-critical systems includes different types of information and communication technology systems, such as wireless (mesh) sensor networks, to carry out control processes in real time.

3.6. Experimental Setup and New Applications

There are huge opportunities to deploy WSNs for real life applications and experimental set-ups. WSNs are being deployed in various application scenarios, including rural and forest environments. Sanchez (2010) designed a WSN based system for generic target (animal) tracking in the surrounding area of wildlife passages. That is built to establish safe ways for animals to cross transportation infrastructures. This deployment is designed on the basis of the IEEE 802.15.4 standard. In environments like fire hazard monitoring, adaptive routing is essential in order to ensure safe and timely data delivery in building evacuation and fire fighting resource applications. The routing protocol presented by Zeng and Xiong (2010) is a robust emergency-adaptive protocol for emergency situations such as building fire hazard applications. This protocol also handles dynamic emergency scenarios and works well with the routing hole problem.

A project name NEURON proposed by Zafeiropoulos (2010), has been developed to reduce the complexity of operation and management, and support the dissemination of knowledge within future WSNs. This is an energy efficient deployment, clustering and routing mechanism in WSNs that focuses on the incorporation of involuntary functionalities in the existing approaches.

Classical sensor network clustering algorithms cannot be used for node clustering for coordination of multimedia sensing and processing. A clustering mechanism proposed by Alaei (2010) for Wireless Multimedia Sensor Networks (WMSNs) is based on overlapped Field of View (FoV). This clustering method conserves energy and prolongs the network lifetime by coordinating the nodes in such a way that avoids the redundant sensing and processing.

Sensor networks can be used as a valuable tool to economize the fuel and to increase the energy efficiency as well without reducing the lifestyle quality. A number of sensors are interconnected

INTERNATIONAL JOURNAL OF APPLIED ENGINEERING RESEARCH, DINDIGUL
Volume 1, No 3, 2010

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REVIEW ARTICLE ISSN - 0976-4259

to form a sensor network within a building. It is tough to deploy a control system in a building because of the various communication standards. Schor *et al.* (2009) designed an architecture that presents a web services-based approach that integrates resource constrained sensor nodes with IP-based networks.

3.7. New Models and Architectures

WSN is a self-organized network of battery-powered wireless sensors that can sense, process, and communicate. We have discussed many technical challenges so far that deserve sincere consideration. These challenges are not limiting the progress in WSNs so much as lack of perfect WSN architecture.

Some of recently developed architectures are discussed here: the environment adaptive and energy efficient capabilities should be integrant for WSN architecture. A hierarchical structure and sub-facets functions architecture model EAWNA is proposed by L. Liu (2010) that also has other objectives like scalability, customized services, environment adaptive and energy efficiency. Conventional network architecture designs are based on layering approach. The idea of the layered architecture can also be used with sensor network architecture design. Cubic and cross-layer (CCL) by C. Lin (2007) is suitable sensor network architecture because of application-specific nature of sensor networks.

Lukkien et al. (2008) proposed Wirelessly Accessible Sensor Populations (WASP) project is to develop an integrated model for implementing applications using WSNs. In this project a model has been developed to program complete WSN as a whole rather than programming individual node because of the inconsistent behavior of individual nodes.

3.8. Holes Problem

Holes are one of the challenges in deployment of WSNs in a large area. Holes generally considered as a communication gap among sensor nodes. Khan and Javed (2008) described various types of holes like Coverage hole, Routing hole, Jamming hole, Sink/Black hole, and Worm hole in their survey work.

3.9. Time Synchronization Problem

Time synchronization in WSN, is to bring the clocks of the sensor nodes together perfect (standard) clock. To bring these clocks together skew and drift of the nodes' clock need to be managed. Main challenge for time synchronization in WSN is to design a light weight, fault tolerant and energy efficient protocol to minimize the energy consumption.

4. Research Challenges

1. *Power:* Power is always been a challenge for WSNs designs. One of the ways to prolong the network lifetime is to design the energy efficient algorithms and hardware that uses power intelligently.

INTERNATIONAL JOURNAL OF APPLIED ENGINEERING RESEARCH, DINDIGUL
Volume 1, No 3, 2010

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REVIEW ARTICLE ISSN - 0976-4259

2. *Hardware Cost:* One of the main challenges is to produce low cost and tiny sensor nodes. Current sensor nodes are mainly prototypes with respect to these objectives. Low cost of sensor nodes can be achieved by recent and future progress in the fields of MEMS.
3. *Security:* Security is one of the major challenges in WSNs. Most of the attacks that are performed on WSN are insertion of false information by compromised nodes within the networks. Development of security schemes for WSN also faces challenges related to constrained environment.
4. *System Architecture:* Researches in the field of WSN is going on around the world but still there is no unified system and network architecture, on the top of that different application can be built.
5. *Real World Protocols:* protocols need to be developed for real world problems considering the theoretical concepts and synthesizing novel solutions into a complete system-wide protocol for real world application.
6. *Analytical and Practical Results:* Till date very few analytical results exists for WSNs. All new applications only get confidence when it is tested & analyzed practically and results are compared with existing schemes.

Table 2: Recent advances and future trends of WSNs.

Area	Applications
Smart Home / Smart Office	Provides custom behavior
Military	Military situation awareness (Shen, 2001), Battlefield surveillance, Sensing intruders, detection of enemy units (Doumit and Agrawal, 2002).
Industrial & Commercial	Monitoring and control of industrial equipment, Manufacturing monitoring.
Traffic Management & Monitoring	traffic congestion control (Chinrungrueng, 2006).
Structural Healthcare	condition-based maintenance (Tiwari, 2004), concrete and composite materials (Arms, 2001).
Topology and coverage control	prolong lifetime, reducing radio interference, increasing the efficiency, graph models of topology control (Jardosh and Ranjan, 2008).
Quality of Service provision	Trade-off between reliablity and energy consumption, delay energy consumption and delay (Abidin, 2009).
Mobility management	NEMO (Devarapalli, 2005), MANEMO (Wakikawa, 2007).
Security and privacy concern	Security in wired and wireless networking, databases and data mining (Li and Das, 2009).
Biomedical / Medical	CodeBlue (Lorincz et al., 2004), ALARM-NET (Wood et al., 2006), AMON (Anliker et al., 2004), GlucoWatch G2 (Dario et al., 2004).
Cognitive sensing	Bio-inspired sensing (Dario, 2004), Swarm intelligence, Quorum sensing.
Spectrum management	Multiple frequencies for parallel communication, Self-Adaptive Spectrum Management (Zhou, 2009).
Underwater acoustic sensor systems	Oceanographic data collection, pollution monitoring, disaster prevention, assisted navigation, tactical surveillance (Akyildiz, 2005).

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Coordination in heterogeneous networks	Connecting the WSN with heterogeneous network, Gateway based interconnection and overlay based interconnection (Liutkevicius, 2010).
Sensing based cyber-physical systems	Collision avoidance, robotic surgery and nano-level manufacturing, search and rescue operation, air traffic control, healthcare monitoring.
Time-critical applications	Real time applications like fire monitoring (Zeng, 2010), border surveillance (Doumit, 2002), medical care, and highway traffic coordination (Chinrungrueng, 2006).
Experimental systems and new applications	WSNs for Oil & Gas, Monitoring Wildlife Passages (Sanchez, 2010),Fire Hazard Monitoring (Zeng, 2010), NEURON, Wireless Multimedia Sensor Networks (Alaei, 2010).
New models and architectures	EAWNA (Liu, 2010), Cubic and Cross-Layer (CCL) (Lin, 2007), WASP) (Lukkien, 2008).

5. Conclusions

The inherent nature of WSNs makes them deployable in a variety of circumstances. They have the potential to be everywhere, on roads, in our homes and offices, forests, battlefields, disaster struck areas, and even underwater in oceans. This paper surveys the application areas where WSNs have been deployed such as military sensing, traffic surveillance, target tracking, environment monitoring, and healthcare monitoring as summarized in Table 2. The paper also surveys the various fields where WSNs may be deployed in the near future as underwater acoustic sensor systems, sensing based cyber-physical systems, time-critical applications, cognitive sensing and spectrum management, and security and privacy management. These application areas are being researched extensively by various people across the industry and academician.

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