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WSN Practical adaptations

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Abstract

Since WSN's have seen tremendous growth in the past few years and have contributed in transforming the society from simple living to smart living. To explore the diverse deployments of WSN, we have studied the various practical deployment applications of WSN in this research work. For each deployment site, we studied its application credentials and technical details related to the deployment site. We feel that this study will not only provide the in-depth knowledge to the learning community, but we will also open the new area of research for rapid commercial deployment of the WSN.

Keywords: WSN, deployment sites, Connectivity, Coverage, Localization, Cross layer design.

Introduction

Due to recent advances in wireless communications and related technologies over the past few years, the manufacturing of small, cheap, low power and multifunctional sensors became technically and economically feasible. The sheer number of these disposable sensors can be deployed in many applications that need unattended operations such as industrial and civilian application areas, including industrial process monitoring and control described by Kay and Mattern (2004), military applications such as battlefield surveillance, environment and habitat monitoring, healthcare applications, home automation, traffic control presented well by Kay & Mattern (2004) and Hadim (2006) and health monitoring described by Tiwari (2007). Wireless Sensor Networks will eventually enable the automatic monitoring of avalanches, forest fires, Tsunami, hurricanes, air pollution, traffic, failure of country wide utility equipment and much more over wide areas which was previously impractical.
This paper is organized as follows:
In Section I, we discuss the structure of a WSN sensor node, various WSN design and deployment issues. The Section II presents the various deployment sites in WSN which shows the efficacy of WSN. In the Section III, we elaborate the ongoing research on WSN. In Section IV, we discuss the future scope. Finally, in Section V, we conclude our paper with final remarks.

Wireless Sensor Network

WSNs are usually composed of sensor nodes (called motes) that communicate wirelessly and have the capabilities of sensing, processing and storing. A Wireless sensor node is a cheap, small, battery powered electronic device designed to monitor or measure a physical phenomenon of the environment around it such as humidity, temperature, pressure, soil, pH, vibration, motion, light, sound, radiation et.al. They are generally composed of microprocessor, the appropriate sensor, a transceiver and a power source.

WSN Node Architecture

A sensor node is made up of four basic components as shown in Fig. 1: a sensing unit, a processing unit, a transceiver unit and a power unit [1]. They may also have application dependent additional components such as a location finding system and a mobilizer.

- **Sensing Unit-** It consists of basically two subunits: Sensors which senses the surroundings or produces the analog signal based on observed phenomenon and analog to digital converters (ADCs) which converts these analog signals into digital one then further these signals fed into the processing unit.
- **Processing unit**- It usually composed of processor and a small storage unit. It reads out the sensor and processes the locally sensed information and implements the various network protocols.
- **Transceiver unit-** It connects the sensor node to the network.
- **Power unit-** It supplies power to the node and supports by a power scavenging unit such as solar cells.
- **Location Finding System-** It gives the accurate knowledge of location of sensor node required in most of routing techniques and sensing task.
- **Mobilizer-** It can be required to move sensor need if there is a need.

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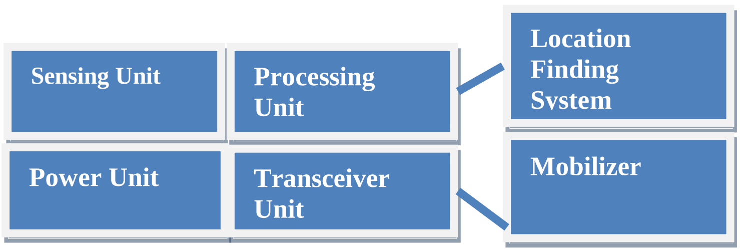

Fig 1: a sample WSN sensor node

WSN Design Issues

A sensor network design is influenced by many factors, which include fault tolerance; production costs; scalability; operating environment; sensor network topology; hardware constraints; transmission media; and power consumption [1]. These factors are addressed by many researchers as surveyed in this paper. However, none of these studies has a fully integrated view of all factors that are driving the design of sensor networks and sensor nodes. These factors are important because they serve as a guideline to design a protocol or an algorithm for sensor networks.

1. Fault tolerance

Sensor nodes can't work properly due to limited power supply, damage in any physical part of a node or environmental interference. The failure of sensor nodes should not incapacitate the entire sensor network. Fault tolerance or Reliability is the ability to sustain the functionalities of network without any interruption due to blockages of sensor nodes. The reliability $R_k(t)$ of a sensor node using the Poisson distribution to capture the probability of not having a failure within the time interval (0, t) is expressed as:

$R_k(t) = \exp(-\lambda_k t)$

Where λ_k is the failure rate of k^{th} sensor node and t is the time limit.

2. Scalability

The number of sensor nodes deployed in a region may be in the range from hundreds to millions depending on the phenomenon under study. They must also utilize the high density nature of the sensor networks. The density, which gives the number of sensor nodes the transmission radius of each node in region A can be computed according to as

$$\mu(R) = (N\pi R^2)/A$$

Where N is the number of sensor nodes in region A and R is the transmission range.

3. Production costs

Since there is a proliferation of sensor nodes, there is a need to justify the cost of a single node to estimate the overall cost of the networks. If currently deployed sensor network cost more than deploying traditional sensor networks, then the network is not cost-justified. Hence, the cost of a sensor node is a very challenging issue given the price of sensor node with all required functionalities much less than a dollar.

4. Hardware constraints

A sensor node consists of four basic units and two additional subunits. All of these subunits should be fitted into a small sized and light weighted module whose size may be lesser than even a cubic centimeter. Apart from the size, there are some other tight constraints for sensor nodes. These sensor nodes must have

- Low power consumption
- High volumetric densities
- Low production cost
- Adaptability due to dynamic nature of network

5. Topology

Topology maintenance becomes a very challenging task due to a myriad of unattended, inaccessible and unreliable sensor nodes. Deploying sheer number of nodes densely requires careful handling of topology maintenance.

6. Environment

Sensor nodes are deployed either within or very close to the deployment site to be observed. However, they work under extremely harsh ambient conditions such as high temperature in debris or a battlefield, high pressure in the bottom of an ocean, low temperature in the nozzle of an aircraft engine or in arctic regions and noisy environment such as under intentional jamming.

7. Transmission media

In a sensor network, sensor nodes communicate using wireless medium such as radio, infrared or optical media. Due to unusual deployment requirements of sensor networks, the choice of transmission media becomes more challenging. For instance, underwater applications may require an aqueous transmission medium where long wavelength radiation can easily penetrate the water surface. Greater interference and error prone channels are encountered by inhospitable terrain or battlefield applications. Hence, the selection of transmission medium must be supported by robust coding and modulation schemes that efficiently model these extensive diverse features of the channel.

8. Power consumption

Power is a scarce resource of energy. Wireless sensor node is a micro-electronic device having limited amount of power supply (<0.5 Ah, 1.2 V). There is a strong dependence between the durability of sensor node and battery lifetime. The failure of sensor nodes can cause a re-organization of the network and significant topological changes and might require routing of packets again. It is for these reasons that the focus of researchers is geared towards the design of power-aware protocols for sensor networks. It is an important performance metric which directly affects the network lifetime.

Deployment Issues

With the goal of facilitating further evolution of wireless sensor networks, recently proposed deployment schemes for wireless sensor networks are surveyed. The focus is on coverage and connectivity, which are regarded as the most important respects of network performance and energy-efficiency. Depending on the application and different actions in the network, coverage issues are classified into static and dynamic ones, while connectivity issues into pure connectivity and routing algorithm based connectivity [2].

- **Connectivity Issue-** Connectivity ensures that all the pairs of nodes can reach for each other. It is classified into two categories named P connectivity or RAB connectivity.
  - **P connectivity-** The basic requirement of the network is ensuring that any pair of arbitrary nodes can communicate with each other. As we know that several routing algorithms such as hierarchical, data centric, location-based, flow oriented and QoS-based are employed for connectivity but it does not depend on these algorithms. It only requires that all the pair of nodes must be connected either directly or through the multiple hops.
  - **RAB connectivity-** Here, various routing algorithms are utilized for making the connection between a particular pair of nodes by considering the energy consumption and the system performance. The main focus is at the connectivity more efficiently through some special energy efficient routing algorithms.
- **Coverage Issue-** In WSN's, each node has the fixed range and the whole monitored area must be sensed through the network. In order to prolong the network lifetime and to make the resource more energy efficient, there is a need of an algorithm that ensures the monitored area can be fully covered. Nowadays it is the main issue that is still remained open today. It is divided into two parts that are static and dynamic.
  - **Static:** Assuming that WSN's architecture does not vary with the development of the network. Several coverage algorithms have been formulated in accordance with initial task requirements and assignments. The main Problem that needs to be resolved is definition of range of sensor nodes and its effect on the entire network.
  - **Dynamic:** In WSN's, coverage should adapt to the changes in the applications and networks such as node disabled, sensing block and tracking mobile object etc. Nowadays density of nodes in the local area can alter according to the actual requirements. We can turn on or off some sensor nodes for saving energy. We can also conserve energy by altering the duty time (i.e. the ratio of active time to sleep time).

Existing Practical deployments

Sensor networks consist of various types of sensors such as seismic, magnetic, thermal, visual, infrared, UW which are able to monitor a wide variety of climatic conditions such as temperature, humidity, pressure et.al. These sensor nodes are used for various tasks such as continuous sensing, event ID, event detection, local control of actuators and location sensing. Here, we present a comprehensive survey of various deployed applications and classifies them into various categories as given in Table 1.

Table1: Various deployment sites uses WSN

Deployment Application	**Brief Description**
Great duck island Project	• Started in 2002 by Dr. Prabhat Ranjan (da-iict, Gandhinagar, University of California, Berkeley). • Build a kit of habitat monitoring (Monitors the microclimates in and around nesting burrows used by the leach‘s storm petrel). • Developed a tiered architecture. • 43 mica motes were deployed [3].
Crop monitoring Project in Kerala	• Here, the authors discussed about monitoring the water level in paddy fields of kuttand, a region of Kerala. • Electro-mechanical sensors were deployed for measuring water level and valves can be transmitted through WSN [4].
Wildfire monitoring	• In this work, authors proposed WSN to address the forest fire problem which was happened on eastern hills in Bogota, Columbia. • They discussed about the Off-the-shelf devices from crossbow. Later on, they stepped to Moteview software that helps in the capturing of temperature and humidity and allows a user to define thresholds on temperature. System generates an alarm if threshold exceeds. • Here, the authors proposed the following techniques which enables monitoring are: ▪ Gas sensing. ▪ Sensing of environmental parameters (fire detection). ▪ Video monitoring (video cameras which ensure the exact location of the potential fire [5].
Underwater acoustic sensor networks	• UASN facilitates applications for oceanographic data collection, ocean sampling, disaster prevention, assisted navigation et.al. • 3d underwater networks having UW-sensor nodes were deployed. UW-sensors are attached to surface buoy so as to adjust the depth of each sensor nodes. • Further, Authors examined the list of various Research Projects in UWSNs were discussed [6].
Landslides Detection	• Here, the authors proposed various distributed clustering and multihop routing protocols for detecting landslides such as CAMP and HBVR. • Further, they enhanced CAMP and HBVR with TEEN, a threshold based event driven protocol which boosts the performance [7].

Tsunami Detection	• In this work, they proposed the three types of nodes: sensor (collect underwater pressure readings), commander (analyze the pressure data and predict which, if any barriers need to fire) and barrier (lessen the impact of wave).Directed diffusion protocol was developed for routing [8].
Detection of emplaced IED (improvised explosive devices)	• Initially, gas sensors and chemical sensors were deployed for the detection during the war in Iraq but they have very high cost and use more Battery power and accuracy. Hence nowadays paper sensors are used. It transmits the acquired data to the processor which further processes the data and compares with the database and if there is a match it enables the buzzer. It traces the vapors of explosives and detects the type of an IED [9].
Health care	• In this work, they proposed a mobile physiological monitoring system which is able to continuously monitor the patient's blood pressure, heart beat and other critical parameters in the hospital. • Initially, Wireless BSN technology was deployed. Later on, they proposed WBSN in OMNet++ simulator and have compared both of them. They observed the proposed system has better performance than others existing WBSN systems [10].
Monitoring Heritage Buildings: The Torre Aquila	• In this work, authors discussed the preservation of the valuable frescoes of Torre Aquila, a medieval tower in Italy which requires real-time monitoring of structural response and environmental conditions. • Fiber optic sensors were used for deformation measurements such as stretching the length of the tower. Custom integration of these sensors with the motes was deployed to report the measurements. • Flash memory usually found is not suited for this task hence they integrated a 32Kbyte FRAM (ferromagnetic RAM) chip. • In addition to above customized hardware, they chose to empower our developers with higher level of abstraction provided by WSN middleware TeenyLIME. System operation (i.e. data dissemination, data collection and time synchronization) were all implemented on the top of that middleware [11].
Monitoring Wildlife Passages	• It includes animal surveillance and tracking techniques. Here, authors deployed a combination of tracking capabilities, provided by infrared motion sensors simultaneously with target identification through the use of camera sensors. • Later on, they developed the detector node using COTS components with its own specific application software. Further they deployed 3G or 4G mobile network [12].
Air Pollution Monitoring	• In this work, authors developed the environmental sensor network. WAPMS (wireless air pollution monitoring system) is an example of such an ESN. • It provides real time information about the level of air pollution as well as provides alerts in cases of drastic change in quality of air. • It uses air quality index to categorize the different levels of air pollution and to evaluate the level of health concern [13].
Urban Traffic Monitoring	• In this work, authors presented the design of wireless traffic monitoring system whose basic components are ▪ A monitoring unit. ▪ Wireless data aggregation sink node uses the information to control traffic light or sends it to the monitoring unit. ▪ Magnetic sensor to detect vehicles and transmit the results to the sink. • Further they discussed about the basic parameters of road states such as traffic volume, velocity and lane occupancy which can also be measured in real time using this system [14].
Smart Home	• Smart Home requires not only monitoring but also reacting on the physical world with high precision and prompt reaction. WSN enriched with actuators to form WSAN. • Further authors proposed a new design for the SH by introducing the wb-sh system which combines two emerging technologies i.e. WSN and biometric. By using biometrics, it is possible to confirm individual's identity based on "who he/she is" rather than "what he/she remembered" (e.g. a password) or "what he/she possesses" (e.g. an id card) [15].
Precision agriculture	• Here, the authors demonstrated implementation of efficient irrigation management system that integrates sensors and actuators using opnet simulation tool. • Further, they proposed the future deployment to focus on the water application efficiency in order to reduce the energy used in irrigation water pumping. • Later on, they promoted the installation of lower-capacity solar PV water pumping systems for irrigations [16].
Volcanic eruption monitoring	• The first field application of WSN for monitoring volcano was in 2004, where four MICA2 nodes were deployed on Volc´an Tungurahua, Ecuador. • Here, the authors designed algorithms that can accurately determine the arrival times of primary waves (i.e. P-waves) received by seismic sensors inside the network, without transmitting raw measurements to the base station for centralized processing. • A dynamic sensor selection problem was formulated to maximize the information quality of picked arrival times for earthquake source localization subject to a bound of data transmission overhead, which can be configured to meet bandwidth limitation, energy budget and real-time performance requirement. Testbed experiments and extensive simulations based on real data traces collected on an active volcano demonstrate the feasibility and effectiveness of our approach [17].
Oil and gas industry	• A market dynamics report released by ONWorld's research in 2012 show that oil & gas exploration, production and pipelines made up 27% of the global industrial WSN market in 2011.In oil and gas industry, data sensed consists of temperature, flow, pressure, vibration, humidity, fire outbreaks, gas leaks, conditions of equipments etc. • Prior to January 2005, International oil and gas companies (IOC) operating in Nigeria Niger delta region made extensive use of wireless technologies. The greatest obstacle or challenge to WSN these days is the issue of security. Different kind of attacks includes oil bunkering and theft, pipeline vandalaisation are obtainable in Niger

	Delta region. • Here, the authors proposed deployment architectures and mechanisms using novelty technologies such as Cyber physical systems (CPS), Wireless Fidelity (Wi-Fi) and low cost CCTV cameras [18].
Logistics	• In this work, authors monitored the conditions of transported goods like tilt, shock, humidity or temperature during transport process with a deployed WSN. • Naturally in the context of storage logistics and transportation logistics, cold chain monitoring and food logistics are a main focus. • Further, they described a test bed at multimedia communication lab (KOM) to evaluate approaches in the context of WSN deployments. They deployed motes in an intelligent container that can monitor environmental parameters [19]. • Here, Authors basically developed an IP based solution, highlighting the use of CoAP (Constrained application protocol) protocol for the retrieval of sensor data during land or sea transportation [20].
Aircraft	• Nowadays, applications in aircraft are manifold e.g. cabin status monitoring, maintenance support, and structural health monitoring and location aware mobile devices. Initially, authors deployed 500 wireless sensor nodes in an Airbus A330-300. • The designed TDMA protocol abstains from multihop and from ARQ-based retransmissions in order to provide guaranteed highest delay together with maximum channel utilization. Robustness is achieved by spatial redundancy provided by multiple APs [21].
Building automation system	• A deployed WSN-based BAS is targeted to operate autonomously for several months or even years. Networked micro sensor technology was used. • Here, the authors studied the key characteristics of wireless communication in BAS including link quality and partition losses and indoor signal attenuation. • Afterwards, they discussed about the MAC Protocols that play a crucial role during energy consumption in sensor network [22].

Ongoing research

Security in WSNs is an upcoming area of research, which is quite different from conventional network security mechanisms. The different directions of ongoing research in WSNs are based on security challenges, including Robustness to Denial-of-Service Attacks, secure routing, Link Layer Security, authentication, Key-Establishment privacy and node capture. Nowadays researchers also focus on the detection of jamming which is the special form of DoS attack as in [25] [26]. In WSN, various techniques such as Link Layer encryption and authentication, identity verification, multipath routing and authenticated broadcast appear to be good solution for security purposes in a WSN. However, attacks such as Wormholes and Sinkhole cause lots of challenges to the design of secure routing protocol. So there exist strong desires of designing such routing protocols in which these attacks are ineffective [23].

Energy optimization at different layer is a very significant research area by reducing the potential energy wastes. In [24], authors utilized the energy at physical layer over the generalized k shadowed fading channel based on BPSK communications. However MAC protocols should be more vulnerable to the movement of nodes. The research community generally ignores mobility at the MAC layer because sensor networks were originally assumed to compromise of static nodes. But recent works like RoboMote have enabled mobility in sensor nodes and there is much room for research in this area. Much research has been conducted to tackle energy consumption at all layers, especially at the network, MAC and physical layers. Cross-layer design can therefore play an important role for the upcoming wireless systems designed for the various applications, featured by all heterogeneous access networks, IP-based protocol stack and multimedia data traffic. One obvious limitation of the two basic network reference models, OSI and TCP/IP, is the lack of information sharing between the protocol layers. A major difference lies between the working of wired and the wireless network architecture because they exploit different protocols which cause the problems like packet loss, delay. Cross-layer design techniques have been used to overcome not only energy restrictions but also to enhance the quality of service and to increase network throughput. There is a need to develop Protocol which can deal both delay and the reliability together. But both terms contradict to each other. These types of researches can open the ways for the new platform in which there is no need to develop the protocols in isolation for the different layers but the concern about their interdependencies can help a lot to solve the existing problems of WSN.

Nowadays, there is strong need to develop new technologies which enable sensors to harvest energy from their surrounding environment such as wind, solar and kinetic energy. Energy Harvesting Wireless Sensor Networks (EH-WSNs) can provide a solution to the many energy problems by harnessing energy that already exists in the surrounding environment and converting it to electrical energy. If the harvested energy source is large then a sensor node can be powered perpetually due to its continuous availability. Cross-layer approaches, Multi-metric protocols and Multi-objective optimization are used to conserve energy [27].

The area of sensor network QoS largely remains an unexplored area of research. It includes: Designing an appropriate QoS model, deciding how many layers need to be integrated, support for heterogeneous nodes, designing QoS model for specific applications, designing QoS based protocols to integrate them with other network like LANs, cellular, optical and IP, and designing QoS through middleware layer [28].

Mobile wireless sensor networks (MWSNs) are a particular class of WSN in which mobility plays an essential role in the execution of the application. Different authors presented a several surveys and taxonomies of localization methods for mobile wireless sensor networks. The most important benchmarks for MWSNs is Reducing localization latency. At present, a tradeoff exists between the rapid execution of an algorithm and its accuracy. Additional work is needed that focused on reducing run-time latency, while maintaining positioning precision. Moreover, the majority of localization algorithms to data are centralized. In recent years, focus of researchers is geared more towards distributed localization techniques in addition to MWSN localization [29].

Conclusion

This paper discusses the various design and deployment issues such as connectivity and coverage issues in WSN. Further, we outlined the various deployment sites from environmental monitoring to military battlefield. The popularity of WSN, in the world, is on the rise in turn creating more opportunities for researchers to work. This work though clearly highlights the ongoing research areas and recent trends in WSN. The field of WSN is rapidly growing and changing and while there are still many areas that need to be uncovered, it is likely that such networks will see widespread use within the next few years.

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