Survey of Wireless Sensor Network Application

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Abstract— Sensor networks offer a powerful combination of distributed sensing, computing and communication. They lend themselves to countless applications and, at the same time, offer numerous challenges due to their peculiarities, primarily the stringent energy constraints to which sensing nodes are typically subjected. The distinguishing traits of sensor networks have a direct impact on the hardware design of the nodes at least four levels: power source, processor, communication hardware, and sensors. Various hardware platforms have already been designed to test the many ideas spawned by the re-search community and to implement applications to virtually all fields of science and technology. We are convinced that CAS will be able to provide a substantial contribution to the development of this exciting field. A wireless sensor network (WSN) has important applications such as remote environmental monitoring 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 with which they can communicate with one another to form a network. The design of a WSN depends significantly on the application, and it must consider factors such as the environment, the application's design objectives, cost, hardware, and system constraints. The goal of our survey is to present a comprehensive review of the recent literature since the publication of [I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, A survey on sensor networks, IEEE Communications Magazine, 2002]. Following a top-down approach, we give an overview of several new applications and then review the literature on various aspects of WSNs. We classify the problems into three different categories: (1) Internal platform and underlying operating system, (2) Communication protocol stack, and (3) Network services, provisioning, and deployment. We review the major development in these three categories and outline new challenges.

***Keywords**:* CAS, IEEE, WSN

I. INTRODUCTION

The increasing interest in wireless sensor networks can be promptly understood simply by thinking about what they essentially are: a large number of small sensing self-powered nodes which gather information or detect special events and communicate in a wireless fashion, with the end goal of handing their processed data to a base station. Sensing, processing and communication are three key elements whose combination in one tiny device gives rise to a vast number of applications [1], [2]. Sensor networks provide endless opportunities, but at the same time pose formidable challenges, such as the fact that energy is a scarce and usually non-renewable resource. However, recent advances in low power VLSI, embedded computing, communication hardware, and in general, the convergence of computing and communications, are making this emerging technology a reality [3]. Likewise, advances in nanotechnology and Micro Electro-Mechanical Systems (MEMS) are pushing toward networks of tiny distributed sensors and actuators.

II. OVERVIEW OF KEY ISSUES

Current state-of-the-art sensor technology provides a solution to design and develop many types of wireless sensor applications. Available sensors in the market include generic (multi-purpose) nodes and gateway (bridge) nodes. A generic (multi-purpose) sensor node's task is to take measurements from the monitored environment. It may be equipped with a variety of devices which can measure various physical attributes such as light, temperature, humidity, barometric pressure, velocity, acceleration, acoustics, magnetic field, etc. Gateway (bridge) nodes gather data from generic sensors and relay them to the base station. Gateway nodes have higher processing capability, battery power, and transmission (radio) range. A combination of generic and gateway nodes is typically deployed to form a WSN.

To enable wireless sensor applications using sensor technologies, the range of tasks can be broadly classified into three groups as shown in Fig. 1. The first group is the system. Each sensor node is an individual system. In order to support different application software on a sensor system, development of new platforms, operating systems, and storage schemes are needed. The second group is communication protocols, which enable communication between the application and sensors. They also enable communication between the sensor nodes. The last group is services which are developed to enhance the application and to improve system performance and network efficiency.

From application requirements and network management perspectives, it is important that sensor nodes are capable of self-organizing themselves. That is, the sensor nodes can organize themselves into a network and subsequently are able to control and manage themselves efficiently. As sensor nodes are limited in power, processing capacity, and storage, new communication protocols and management services are needed to fulfill these requirements.

The communication protocol consists of five standard protocol layers for packet switching: application layer, transport layer, network layer, data-link layer, and physical layer. In this survey, we study how protocols at different layers address network dynamics and energy efficiency. Functions such as localization, coverage, storage, synchronization, security, and data aggregation and compression are explored as sensor network services.

Implementation of protocols at different layers in the protocol stack can significantly affect energy consumption, end-to-end delay, and system efficiency. It is important to optimize communication and minimize energy usage.

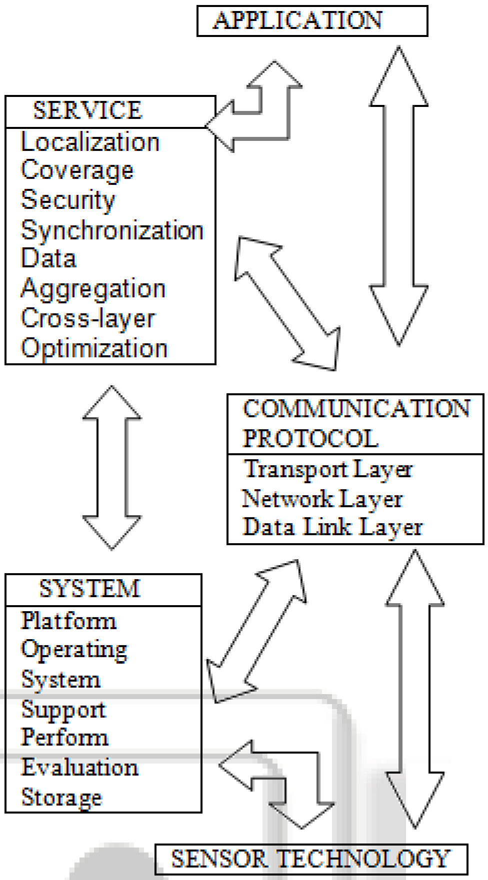

Fig. 1: Broad classification of varios issues in a WSN

Traditional networking protocols do not work well in a WSN since they are not designed to meet these requirements. Hence, new energy-efficient protocols have been proposed for all layers of the protocol stack. These protocols employ cross-layer optimization by supporting interactions across the protocol layers. Specifically, protocol state information at a particular layer is shared across all the layers to meet the specific requirements of the WSN.

As sensor nodes operate on limited battery power, energy usage is a very important concern in a WSN; and there has been significant research focus that revolves around harvesting and minimizing energy. When a sensor node is depleted of energy, it will die and disconnect from the network which can significantly impact the performance of the application. Sensor network lifetime depends on the number of active nodes and connectivity of the network, so energy must be used efficiently in order to maximize the network lifetime.

Energy harvesting involves nodes replenishing its energy from an energy source. Potential energy sources include solar cells [4,5], vibration [6], fuel cells, acoustic noise, and a mobile supplier [7]. In terms of harvesting energy from the environment [8], solar cell is the current mature technique that harvest energy from light. There is also work in using a mobile energy supplier such as a robot to replenish energy. The robots would be responsible in charging themselves with energy and then delivering energy to the nodes. Energy conservation in a WSN maximizes network lifetime and is addressed through efficient reliable wireless communication, intelligent sensor placement to achieve adequate coverage, security and efficient storage management, and through data aggregation and data compression. The above approaches aim to satisfy both the energy constraint and provide quality of service (QoS)[2] for the application. For reliable communication, services such as congestion control, active buffer monitoring, acknowledgements, and packet-loss recovery are necessary to guarantee reliable packet delivery. Communication strength is dependent on the placement of sensor nodes. Sparse sensor placement may result in long-range transmission and higher energy usage while dense sensor placement may result in short-range transmission and less energy consumption. Coverage is interrelated to sensor placement. The total number of sensors in the network and their placement determine the degree of network coverage. Depending on the application, a higher degree of coverage may be required to increase the accuracy of the sensed data. In this survey, we review new protocols and algorithms developed in these areas.

III. APPLICATION

WSN applications can be classified into two categories: monitoring and tracking (see Fig. 2). Monitoring applications include indoor/outdoor environmental monitoring, health and wellness monitoring, power monitoring, inventory location monitoring, factory and process automation, and seismic and structural monitoring. Tracking applications include tracking objects, animals, humans, and vehicles. While there are many different applications, below we describe a few example applications that have been deployed and tested in the real environment.

PinPtr [2] is an experimental counter-sniper system developed to detect and locate shooters. The system utilizes a dense deployment of sensors to detect and measure the time of arrival of muzzle blasts and shock waves from a shot. Sensors route their measurements to a base station (e.g., a laptop or PDA) to compute the shooter's location.

Sensors in the PinPtr system are second-generation Mica2 motes connected to a multi-purpose acoustic. sensor board. Each multi-purpose acoustic sensor board is designed with three acoustic channels and a Xilinx Spartan II FPGA. Mica2 motes run on a TinyOS [10] operating system platform that handles task scheduling, radio communication, time, I/O processing, etc. Middleware services developed on TinyOS that are exploited in this application include time synchronization, message routing with data aggregation, and localization.

Microscope of redwood [11] is a case study of a WSN that monitors and records the redwood trees in Sonoma, California. Each sensor node measures air temperature, relative humidity, and photo-synthetically-active solar radiation. Sensor nodes are placed at different heights of the tree. Plant biologists track changes of spatial gradients in the microclimate around a redwood tree and validate their biological theories.

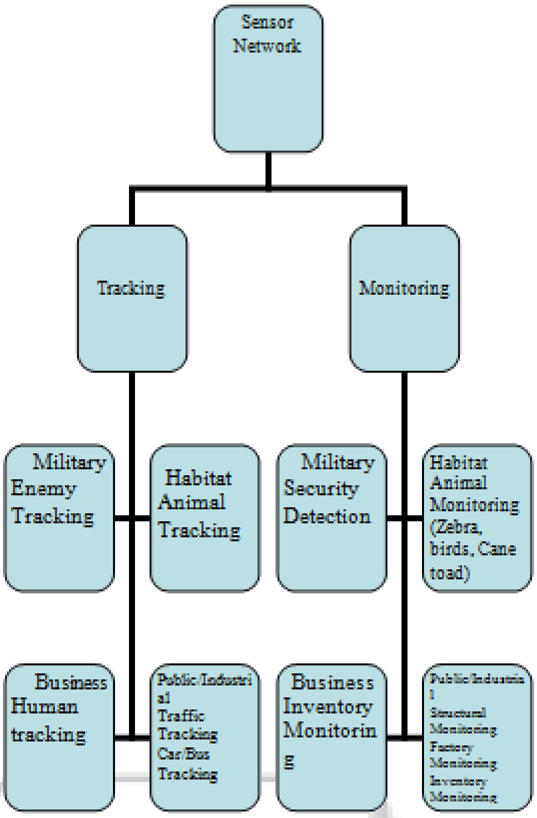

Fig. 2: Overview of sensor network

Semiconductor plants and oil tanker application reported in [12] focus on preventive equipment maintenance using vibration signatures gathered by sensors to predict equipment failure. Based on application requirements and site survey, the architecture of the network is developed to meet application data needs. Two experiments were carried out: the first was in a semiconductor fabrication plant and the second on an onboard oil tanker in the North Sea. The goal was to reliably validate the requirements for industrial environments and evaluate the effect of the sensor network architecture. The study also analyzed the impact of platform characteristics on the architecture and performance of real deployment.

Underwater monitoring study in [13] developed a platform for underwater sensor networks to be used for long term monitoring of coral reefs and fisheries. The sensor network consists of static and mobile underwater sensor nodes. The nodes communicate via point-to-point links using high speed optical communications. Nodes broadcast using an acoustic protocol integrated in the TinyOS protocol stack. They have a variety of sensing devices, including temperature and pressure sensing devices and cameras. Mobile nodes can locate and move above the static nodes to collect data and perform network maintenance functions for deployment, re-location, and recovery. The challenges of deploying sensors in an underwater environment were some key lessons from this study.

MAX [14] is a system for human-centric search of the physical world. MAX allows people to search and locate physical objects when they are needed. It provides location information reference to identifiable landmarks rather than precise coordinates. MAX was designed with the objectives of privacy, efficient search of a tagged object, and human-centric operation. MAX uses a hierarchical architecture that requires objects to be tagged, sub-stations 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 public or owner only. 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.

Connection-less sensor-based tracking system using witness (CenWits) [15] is a search-and-rescue system designed, implemented, and evaluated using Berkeley Mica2 sensor motes. The system uses several small radio frequencies (RF)-based sensors and a small number of storage and processing devices. CenWits is not a continuously-connected network. It is designed for intermittent network connectivity. It is comprised of mobile sensors worn by subjects (people), access points that collect information from these sensors and GPS receivers, and location points to provide location information to the sensors. A subject will use the GPS receivers and location points to determine its current location. The key concept is the use of witnesses to convey a subject's movement and location information to the outside world. The goal of CenWits is to determine an approximate small area where search-and-rescue efforts can be concentrated.

Cyclops [16] is a small camera device that bridges the gap between computationally-constrained sensor nodes and complimentary metal-oxide semiconductor (CMOS) imagers. This work provides sensor technology with CMOS imaging. With CMOS imaging, humans can (1) exploit a different perspective of the physical world which cannot be seen by human vision, and (2) identify their importance. Cyclops attempts to interface between a camera module and a lightweight sensor node. Cyclops contains programmable logic and memory circuits with high speed data transfer. It contains a micro-controller to interface with the outside world. Cyclops is useful in a number of applications that require high speed processing or high resolution images.

WSN in a petroleum facility [17] can reduce cost and improve efficiency. The design of this network is focused on the data rate and latency requirement of the plant. The network consists of four sensor node and an actuator node. The sensor nodes are based on T-mote sky devices [18]. Two AGN1200 pre-802.11N Series MIMO access points [19] are used to create an 802.11b 2.4 GHz wireless local area network. In this multi-hop WSN, the T-mote sky devices send their radio packets to the base station which is forwarded to a crossbow star gate gateway. The crossbow star gate gateway translates the radio packets and sends it along the Ethernet MIMO to a single board TS-3300 computer [20]. The single board TS-3300 computer outputs the sensor data to the distributed control system. The distributed control system can also submit changes to the actuator. In this study, results of network performance, RSSI and LQI measurement and noise were gathered. Results show that the effect of latency and environmental noise can significantly affect the performance of a WSN placed in an industrial environment.

Volcanic monitoring [21] with WSN can help accelerate the deployment, installation, and maintenance process. WSN equipments are smaller, lighter, and consume less power. The challenges of a WSN application for volcanic data collection include reliable event detection, efficient data collection, high data rates, and sparse deployment of nodes. Given these challenges, a network consists of 16 sensor nodes was deployed on Volcàn Reventador in northern Ecuador. Each sensor node is a T-mote sky device [18] equipped with an external omni directional antenna, a seismometer, a microphone, and a custom hardware interface board. Of the 16 sensor nodes, 14 sensor nodes are equipped with a single axis Geospace Industrial GS-11 Geophone with corner frequency of 4.5 Hz while the other two sensor nodes carried triaxial Geospace Industries GS-1 seismometers with corner frequencies of 1 Hz. The custom hardware interface board was designed with four Texas Instruments AD7710 analog-to-digital converters to integrate with the T-mote sky devices. Each sensor node draws power from a pair of alkaline D cell batteries. Sensor nodes are placed approximately 200–400 m apart from each other. Nodes relay data via multi-hop routing to a gateway node. The gateway node connected to a long-distance Free-Wave radio modem transmits the collected data to the base station. During network operation, each sensor node samples two or four channels of seismic acoustic data at 100 Hz. The data is stored in local flash memory. When an interesting event occurs, the node will route a message to the base station. If multiple nodes report the same event, then data is collected from the nodes in a round-robin fashion. When data collection is completed, the nodes return to sampling and storing sensor data locally. In the 19 days of deployment, the network observed 230 eruptions and other volcanic events. About 61% of the data was retrieved from the network due to short outages in the network from software component failure and power outage. Overall, the system performed well in this study.

Health monitoring applications [9] using WSN can improve the existing health care and patient monitoring. Five prototype designs have been developed for applications such as infant monitoring, alerting the deaf, blood pressure monitoring and tracking, and fire-fighter vital sign monitoring. The prototypes used two types of motes: T-mote sky devices [18] and SHIMMER (Intel Digital Health Group's Sensing Health with Intelligence, Modularity, Mobility, and Experimental Re-usability).

Because 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 the parent when the infant is lying on its stomach. Sleep Safe consists of two sensor motes. One SHIMMER mote is attached to an infant's clothing while a T-mote is connected to base station computer. The SHIMMER node has a three-axis accelerometer for sensing the infant's position relative to gravity. The SHIMMER node periodically sends packets to the base station for processing. Based on the size of the sensing window and the threshold set by the user, the data is processed to determine if the infant is on their back.

Baby Glove prototype is designed to monitor vitals. Baby Glove is a swaddling baby wrap with sensors that can monitor an infant's temperature, hydration, and pulse rate. A SHIMMER mote is connected to the swaddling wrap to transmit the data to the T-mote connected to the base station. Like Sleep Safe, an alert is sent to the parent if the analyzed data exceeds the health settings. Fire Line is a wireless heart rate sensing system. It is used to monitor a fire fighter's heart rate in real-time to detect any abnormality and stress. Fire Line consist of a Tmote, a custom made heart rate sensor board, and three re-usable electrodes. All these components are embedded into a shirt that a fire fighter will wear underneath all his protective gears. The readings are taken from the T-mote is then transfer to another T-mote connected to the base station. If the fire fighter's heart rate is increasing too high, an alert is sent.

Heart@Home is a wireless blood pressure monitor and tracking system. Heart@Home uses a SHIMMER mote located inside a wrist cuff which is connected to a pressure sensor. A user's blood pressure and heart rate is computed using the oscillometric method. The SHIMMER mote records the reading and sends it to the T-mote connected to the user's computer. A software application processes the data and provides a graph of the user's blood pressure and heart rate over time.

LISTSENse enables the hearing impaired to be informed of the 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 place near objects (e.g., smoke alarm and doorbell) that can be heard. Transmitter motes consist of an omni-directional condenser microphone. They periodically sample the microphone signal at a rate of 20 Hz. If the signal is greater than the reference signal, an encrypted activation message is sent to the user. The base station T-mote receiving the message actives the vibrator and its LED lights to warn the user. The user must press the acknowledge button to deactivate the alert.

ZebraNet [5] system is a mobile wireless sensor network used to track animal migrations. ZebraNet is composed of sensor nodes built into the zebra's collar. The node consists of a 16-bit TI microcontroller, 4 Mbits off-chip flash memory, a 900 MHz radio, and a GPS unit. Positional readings are taking using the GPS and sent multi-hop across zebras to the base station. The goal is to accurately log each zebra's position and use them for analysis. A total of 6–10 zebra collars were deployed at the Sweet waters game reserve in central Kenya to study the effects and reliability of the collar and to collect movement data. After deployment, the biologists observed that the collared zebras were affected by the collars. They observed additional head shakes from those zebra in the first week. After the first week, the collared zebra show no difference than the uncolored zebra. A set of movement data was also collected during this study. From the data, the biologists can better understand the zebra movements during the day and night.

IV. Conclusion

Sensor networks offer countless challenges, but their versatility and their broad range of applications are eliciting more and more interest from the research community as well as from industry. Sensor networks have the potential of triggering the next revolution in information technology. The challenges in terms of circuits and systems are numerous: the development of low-power communication hardware, low-power microcontrollers, MEMS based sensors and actuators, efficient AD conversion, and energy scavenging devices is necessary to enhance the potential and the performance of sensor networks. System integration is another major challenge that sensor networks offer to the circuits and systems research community. We believe that CAS can and should have a significant impact in this emerging, exciting area.

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