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Introduction to Practical Deployments on Wireless Sensor Networks

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***Abstract*—In the recent years there have been many published papers related on sensors. We can say that it is one of the hot topics of the last decades. But, the more we read, the more we realize that almost all are theoretical proposals or new theories. Very few works show real sensor networks deployments. While sensor network surveys show their benefits and the fields where they can be applied, they don't show who, how and where they have been deployed. In this paper, we are going to explain which motivation has roused us to create this special issue, and we will provide the main steps that a practical deployment should follow to be implemented. Then, we will introduce all the papers that have been selected to be published in this issue.**

Keywords-Wireless Sensor Networks, Practical Deployments, Real-world Implementations.

I. INTRODUCTION

Sensor has been a hot topic since the 90's [1]. The more parameters are needed to be measured from the environment, the more sensors have been deployed. Wireless Sensor Networks (WSNs) provide a self-configured and a self-powered wireless infrastructure for any type of environment. In order to build a WSN, the technology to join many of these sensors must be provided. In the late 90's, many theories and protocols were proposed for WSNs [2][3][4]. The main issues discussed in those works were the first three network layers. In the first layer, the physical layer, researchers proposed new wireless technologies for the sensors with the main objective of providing communication with low power consumption. In the second layer, where the medium access control protocols are placed, many researchers proposed new methods about how the wireless sensor devices have to see each other and establish a network topology [5][6]. In the third layer, many researchers focused their efforts on designing and developing new routing algorithms to route the information inside the wireless sensor network in an efficient manner and saving energy.

In all research fields related with WSNs, the main issues taken into account have been the low processing capacity, few computing resources and their energy limitation. Many more new theories appeared in the beginning of the 2000 [7][8]. Moreover, many researchers improved the WSN protocols and systems in existence. During the 2000, the technology advanced enough to create small devices with enough computing capacity and with low power consumption while being able to sense the environment [9][10]. We can see how WSN can benefit developing countries [11]. Moreover, the last researches have been focused on developing upper layer protocols for WSNs such as multimedia [12], transport layer protocols [13], etc.

Many articles show the wide range of application environments of the WSNs [14], but very few were about real implementations, compared to the amount of theoretic published works.

WSN lifecycle is formed by different differentiated steps. The first step is to know what the application of the WSN is. The second step is to design (or choose the appropriate) the hardware of the sensor node, its operative system, the system architecture, the wireless technology used by the nodes, the medium access protocol for all nodes and the routing protocol used in the sensor network. The third step is to implement the WSN in a testbench. WSN test is the fourth step. It should be performed in order to check its proper operation and its performance. The fifth step us the deployment of the WSN in the real world. Once, the WSN is running, its maintenance and continuous monitoring should be taken into account. Figure 1 shows the steps followed in the WSN. The peculiarity of the WSN lifecycle versus others is the number of disperses topics taken into account during the design step and the difficulty of the deployment step because of the number of devices and topics tackled.

In the beginning, there were some works published proposing algorithms and strategies for practical WSN deployment in terms of sensing coverage area [15][16], better detection and sensing range [17], the radio coverage [18][19], the optimal deployment based on the physical layer [20], the cost and lifetime [21], the topology control [22], energy saving issues [23], probability of target detection [24], and the scalability [25]. Later, some authors published a work with a theoretic analysis for the WSN deployment [26] and there was another work published about how to check the quality of the WSN deployments [27]. But, all of these papers are theoretic works.

We can also find in the literature some papers whose authors discuss the design and deployment issues [28], others that explain the WSN deployment procedure [29], and surveys about the steps that it should be made for a proper deployment [30]. Nowadays, there are studies about how the wireless technology affects to the deployment [31]. Others use the real world to test and validate their proposals [32], and even propose a deployment time validation consisting of techniques and procedures for WSN status assessment and verification [33]. Some authors state that the Self-Monitoring and Self-Configuration are the main keys for the WSN deployment success [34]. There is also a work that shows the development of robots to put the sensor nodes carefully in the appropriated place [35].

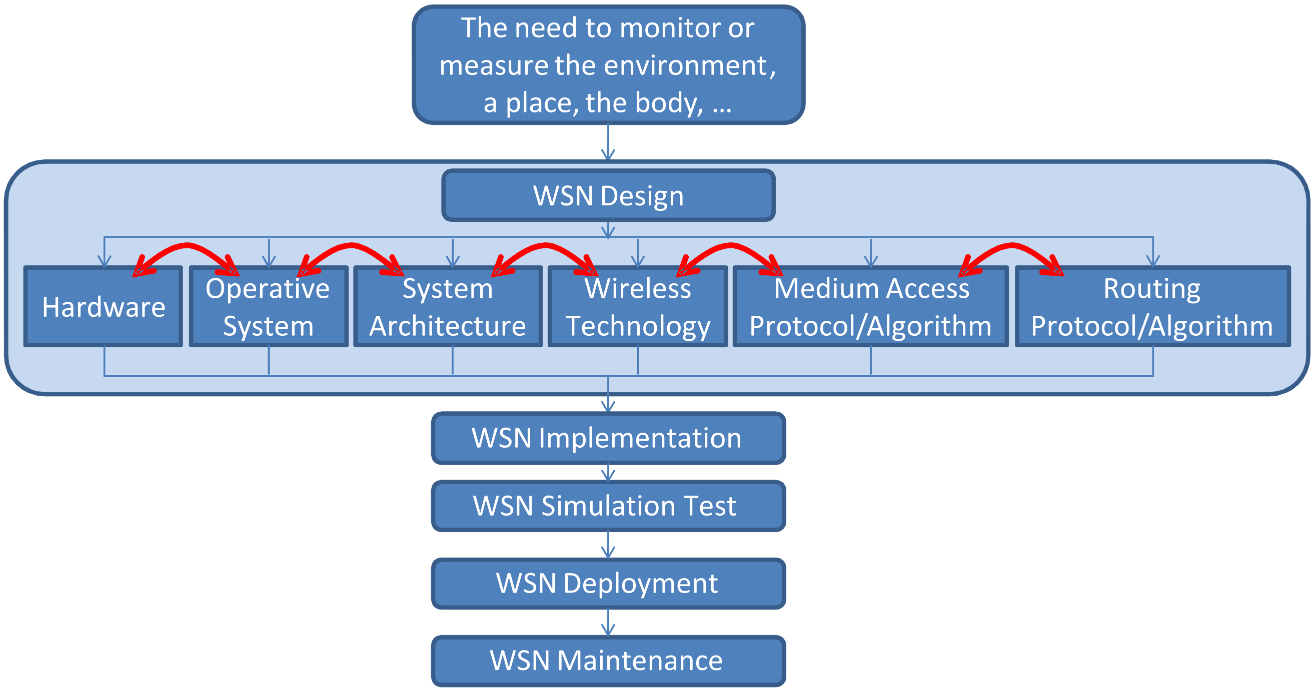

Figure 1. WSN lifecycle.

Finally, some software applications have been developed for designing WSNs, such as the one presented in [36], and for monitoring and control the WSN once it has been deployed [37][38].

The remainder of the paper is structured as follows. Section II shows some related work and explains our motivation to create this special issue. The papers selected for this special issue are described in Section III. Finally, Section IV provides the conclusions.

II. Related Work and Motivation

Along the years, there have been many conferences where one of the topics has been the deployment of the WSN. But, very few papers related with WSN deployments can be found between the papers published in their proceedings. Some examples of WSNs deployments found in some conferences are: for the agriculture [39], for a petroleum environment [40], for a Semiconductor Plant [41], for Coastal Marine Environments [42], for bridge monitoring [43], and for monitoring heritage buildings [44]. Although we can find one paper about the deployments performed by a research centre (in this case CSEM [45]), it is very rare to find such type of papers between the published papers. But, the Sensor-specialized conferences that have been differentiated because of the amount of papers published about practical deployments along the years, up to 2010, have been RealWSN (its first event is referenced in [46]) and, one of the biggest ones, SENSORCOMM (its first event is referenced in [47]), both having four past events. Others have disappeared or focused on more topics.

When we search for research books related with WSN deployments, we can see that there is no book focused exclusively on it, and, moreover, very few works about WSN deployments are published in books.

When we have a look at the research journals, we can find some sporadic paper publications. Some examples are: a deployment for structural monitoring [48], a deployment for management of irrigation [49] and a deployment of rural and forest fire detection system [50]. We have not seen any topic related with WSN deployments or real WSN experiences in any international journal. In the recent months, some call for papers for Special Issues of international journals have appeared with the topic WSN deployments such as the one called "Special Issue on Mobility in Wireless Sensor Networks" in [51], but it will be published in mid 2011. Moreover, we have found a Special Issue focused on with the main topic WSN Real-World Deployments and Deployment Experiences, but it will be published at the end of 2010. To the extent of our knowledge, there is not any Special Issue related with WSN deployments before the publication of this issue.

III. Papers Selected

This section describes the papers published in this special issue. We have selected 15^{th} papers. They can be ordered in 4 parts. The first part shows WSN deployments in agricultural, rural and forest environments. Four papers have been selected to cover it. The second part shows four WSN deployments for healthcare and human assistance. The third part is formed by 2 papers about WSN deployments in oceanography and marine zones. The last part is formed by several types of WSN deployments. This part is ended by a survey of WSN deployments found in the related literature.

A. Part 1: Deployments in agricultural, rural and forest environments

In the first paper of this special issue, C. Anand et al. present "Wireless multi-sensor embedded system for Agro-industrial monitoring and control". The paper shows the development of a low cost multi sensor embedded system for measuring up to eight input analog sensor parameters along with reconfigurable automation, and communicating with host (wired and wireless), optimized by appropriate algorithms. The developed system has been deployed with resistance temperature detector (RTD) sensors, for temperature measurement, decision-making and their control in order to reduce the false alarms and unwanted process shut downs. Moreover, a mobile robotic platform is developed to test the multi-sensor embedded system for Agro-Industrial Applications (such as grain and fruit storage, vegetable storage smart pond automation for fresh aquaculture and so on). It has been also successfully tested to monitor the soil parameters in the farm and transmit the data to the central system using wireless protocol for precision agriculture. The data sent using wireless communication allows the system to be efficient and effective. It also allows making intelligent decisions based on the processed data. Furthermore, the average loss in signal is measured and received power is calculated and compared. The authors observed that for better transmission of signals via wireless communication, the low frequency along with low baud rate and line of sight range is required to minimize the signal loss.

The second paper, "Distributed Monitoring Systems for Agriculture based on Wireless Sensor Network Technology", authored by D. Di Palma et al., presents the design, optimization and development of an application to the agrofood chain monitoring and control. The authors try to reach the best architectural solutions with particular focus on hardware implementation and communication protocol design. The overall system was addressed in terms of the experienced platform, network issues related both to communication protocols between nodes and gateway operations up to the suitable remote user interface. They show the results given by several pilot sites in different vineyards throughout Italy and France. Finally, they present the commercial system "VineSense", based on WSN technology and oriented towards market and user applications. It was born from their previous experiments. At last, some important agronomic results achieved by the use of VineSense in different scenarios were sketched out, thus emphasizing the positive effects of the WSN technology in the agricultural environment.

The third paper is titled "Evaluation of Environmental Wireless Sensor Network - Case Foxhouse" and is authored by I. Hakala et al. This paper describes the implementation of an environmental monitoring system in a Foxhouse. They use a WSN in order to collect real-time data (luminosity, temperature and humidity) in hard outdoors conditions over a period of one year. In this paper they evaluate the communication over IEEE802.15.4, by providing and analyzing the throughput and the link quality statistics. They also present the power consumption measurements and discuss the observations performed.

The paper "Infrared wireless network sensors for imminent forest fire detection", authored by I. Bosch and L. Vergara, is the fourth paper. It presents an automatic forest fire surveillance ground system applied to early fire detection based on several sensors strategically located to render a required coverage. The images obtained from an infrared sensor network are processed by advanced thermal image processing techniques with the purpose of determining the presence of fire. The sensor wireless network supervises remotely the wide-forest area in order to detect immediately any fire threat. It provides total control of a tolerable level of false alarms and has maximum sensitivity to the presence of an uncontrolled fire for the defined false-alarm rate. The authors present some results obtained from a real environment in order to corroborate the control of the probability of false alarm and to evaluate the probability of detection dependence on signal to noise ratio. The delays of the system for alarm detection of controlled fire are also evaluated in order to show the performance of the system in the real environment.

B. Part 2: Deployments for healthcare and human assistance

P. Bustamante et al. present the fifth paper "A new Wireless Sensor for Intravenous Dripping Detection". This paper presents a WSN deployment for Intravenous Dripping System, which can detect when an intravenous liquid, provided to patients in hospitals, run out, as well as detecting obstructions in the catheter. The system allows more efficient and immediate attention in sanitary centers because the observation of the state of the container will not need human supervision. They paid attention to the reduction in consumption in comparison to other wireless devices with the same characteristics, the low cost of the wireless devices, the size of the devices, the flexibility forming the network, and the scalability of the system.

The sixth paper is authored by K. F. Navarro et al. with title "A Distributed Network Management Approach to WSN in Personal Healthcare Applications". It describes the development of a WSN for personal health monitoring system called Medical MoteCare. It uses a combination of medical and environmental sensors in an inherent network management distributed environment for the handling of medical data for patients. The use of SNMP and CodeBlue agents and a tailored MIB enhanced the scalability, modularity and flexibility of the system by potentially bringing the freedom of selecting from a vast range of existing SNMP based network management tools (such as the network management software Jaguar SX, iReasoning MIB Browser, and SysUpTime Network Monitor) to fit their specific WSN application requirements. Network management tools provide data storage correlation and dissemination as well as timely alerts when parameters are breached. They implemented JaguarSX in order to add intelligence to the system by utilizing network management correlation techniques that interpret the collected events automatically and react, or sometimes even anticipate from the collected statistical data, to harmful health conditions.

The paper "Design and Implementation of Multi-User Wireless Body Sensor Networks", by J. A. Afonso et al. is the seventh paper. It describes the design and development of two multi-user low power wireless body sensor network (BSN) that allow the real-time monitoring of wearable sensors data of several users with a single central monitoring unit (base station). They use inertial sensors that allow the monitoring of users' posture, goniometric development, movement as well as heart rate and respiratory rate sensors. Both BSNs present differences in the architecture, wireless network hardware and implemented protocols. They took into account the requirements of quality of service provisioning and low energy consumption. Their results show that their system provides good bandwidth efficiency and decreases the delivery error rate without significant increase in the energy consumption. The system can be used for the monitoring of teams of athletes in a gymnasium for sports with the goal of providing detailed information in order to enhance the performance of both the athletes individually and the team as a whole, and it can also be used for the medical field, namely in physiotherapy sessions, where such a system can benefit both the patient, by increasing his levels of confidence, and the therapist, by providing detailed information about the patient evolution.

In the eighth paper, "Human-Assisted Calibration of an Angulation based Location Indoor System with Preselection of Measurements", J. Kemper et al. present a software aided approach for the calibration of a triangulation-based indoor location system. The aim of their approach is to significantly reduce the calibration effort of the system by automating the process of node localization. The system estimates the localization of the sensor nodes using an algorithm based on the Newton-Raphson method for solving non-linear equation systems. It uses a passive sensor technology. The sensor nodes are equipped with infrared sensors only. As infrared radiation does not penetrate walls, the location system is limited to one room and the number of required sensors is small. Node localization is realized without any prior knowledge of sensor positions, orientations or the location of the moving person. The system has been implemented using a location system that exploits the thermal radiation of humans for localization. The algorithm works fine under the influence of noise. Moreover, an increased number of source locations improve the node localization accuracy.

C. Part 3: Deployments in oceanography and marine zones

O. Bondarenko et al. authored the ninth paper: "Deployment of Wireless Sensor Network to Study Oceanography of Coral Reefs". They deployed a WSN for in situ monitoring the Coral Sea and upwelled on the reef. The array of underwater sensors was deployed at various depths on the coral reef in Nelly Bay, Magnetic Island, Great Barrier Reef Australia (GBR). They used the temperature and 3D dense spatial data to correctly describe upwelling and their impact on plankton abundance (they collect the plankton data in real time synchronized to the temperature changes). The temperature data are sent in real time via the ad hoc network using RF signal to the on-shore base station. They also deployed dataloggers to collect temperature data from the same location. They used the WSN to demonstrate that short term stratification can occur in shallow tropical waters and influence the distribution of plankton.

The tenth paper is "Target Tracking in Marine Wireless Sensor Networks", by A. M. Mahdy and J. M. Groenke. They describe the main underwater tracking algorithms and thoroughly present a perspective on target tracking in marine WSNs. They also show the major challenges and applications about the deployment of underwater WSNs. Then, they present a two-layer broadband wireless infrastructure for marine/terrestrial sensor networks with military, inhabit monitoring, and homeland security applications. This paper has been included in this special issue because of the practical point of view provided in this work.

D. Part 4: Several types of deployments

The paper "An Integrating Platform for Environmental Monitoring in Museums Based on Wireless Sensor Networks", by L. M. Rodríguez and L. M. Pestana, is the eleventh paper. They present a WSN deployment for automatically and continuously monitoring the environment (temperature, humidity and light, throughout the day and night) of a Contemporary Art Museum located in Madeira Island, Portugal. They developed a new wireless sensor node that allow to automatically control real-time the dehumidifying, maintaining the humidity at more constant levels. They found some problems related with the signal propagation (because of the building walls where the WSN is being deployed), and with the hardware characteristics and resource limitations of the sensor nodes.

D. Bri et al. authored the twelfth paper: "A Wireless IP Multisensor Deployment". They present the deployment of a Wireless IP multisensor that uses IEEE 802.11b/g standard. It is able to gather several types of data from the environment and transmit the result of their combination. It is flexible and it could be adapted to any type of environment and to any type of physical sensor with a serial output. They took into consideration its development costs, its expansion capacity, the possibilities provided by the operating system, and its flexibility to add more features to the sensor node. Finally, they compared it with other existing sensors in the market.

The thirteenth paper is authored by F. Kerasiotis et al. In their work "Evaluation of Outdoor RSS-Based Tracking for WSNs Aiming at Topology Parameter Ranges Selection" they use the received signal strength (RSS), of the exchanged messages, for outdoor localization and tracking application under well defined topology constraints. They combine target tracking considerations by means of tracking techniques, topology parameters and factors influencing the tracking accuracy. Their study was focused on identifying the most crucial RSS-based tracking problems and to determine and evaluate the topology parameters that can guarantee successful tracking. The real outdoor tracking test demonstrates that the RSS can be used for outdoor localization and tracking applications under well-defined topology constraints and only after the proper calibration.

The paper "Deployment Considerations for Reliable Communication in Wireless Sensor Networks", authored by T. Stoyanova et al., is the fourteenth paper selected for this special issue. In this work, the authors study the deployment factors and requirements, which can ensure reliable communication links among the sensor network nodes. They used a RF signal propagation-based connectivity algorithm (RFCA), which utilizes an outdoor RF signal propagation model for predicting the RSS in the positions (based on the RF frequency, transmission power, transmitter–receiver distance, height from the ground and antenna's characteristics such as gain, polarization and orientation, etc.), where sensor nodes are supposed to be deployed. The RFCA is able to find the most appropriate, from the communication point of view, deployment parameters (height from the ground, T-R distance, and transmission power) for positioning the sensor nodes in outdoor environment in order to guarantee reliable connectivity level and minimize the interference from non-neighbor nodes. Finally, real outdoor measurements are compared with the simulation results for the verification of their RF propagation models.

Finally, the fifteenth paper selected has been "Practical Deployments of Wireless Sensor Networks: a Survey", by M. Garcia et al. The paper is focused on classifying applications of WSNs and describing real implementations. The goal of the authors is to complement the existing surveys, by presenting details of real implementations and practical deployments in order to understand how these networks run, and how they are designed, maintained and operated. Finally, the authors compare them in terms of network size, technology used, the communication type, single/multiple use and the domain where they are applied.

IV. Conclusion

In this special issue, we have seen a great variety of WSN deployments. We observed that the problems found in the real world could make the wireless sensor network deployment a difficult task. The WSN must be adapted to the environment in order to take the most advantage of them.

We hope the reader enjoys the papers published in this special issue and learns from the experiences provided by the authors in these papers.

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