Basic Guidelines for Deploying Wireless Sensor Networks in Agriculture

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Abstract— **This paper provides basic guidelines for deploying Wireless Sensor Networks (WSNs) in Agriculture, and more specifically in applications requiring crop monitoring. Firstly, it reviews the main components that existing WSN applications use, namely node platforms, operating systems (OSs), power supply, etc. Based on these data, a generic guide is proposed discussing basic considerations for deploying WSNs in applications relevant to agriculture.**

I. INTRODUCTION

Recently, the Agriculture domain has incorporated wireless sensor networks (WSNs) to support its operations. Following this, Precision Agriculture (PA) started to flourish. Precision Agriculture is the science of precise understanding, estimating and evaluating crops condition with the aim of determining the proper use of fertilizer and the real needs of irrigation both through sowing and harvesting period [1]. All these functions can be realized using new technologies such as satellite imagery, geospatial tools and recently, the wireless sensor networking technology [2]. Horticulture can also benefit from the use of this technology [1].

A wireless sensor network is an ad-hoc network, generally, as it does not require the existence of infrastructure like wires to operate. It consists of a few to dozens and in some cases thousands of sensor nodes such as the ExScal project, connected to one or more sensors [3]. It also includes a Base Station (BS), which acts as gateway between the WSN and the end users. A basic WSN deployment for agricultural purposes is depicted in Figure 1. As it can be seen, the WSN consists of scattered and densely deployed sensor nodes in a field with the BS being set in the middle. The dotted lines represent the wireless multi-hop connection between the nodes.

Many WSN applications have been proposed so far in PA, which include monitoring vineyards in Italy and Spain to various fruits and vegetables as well as plant cultivation in rural areas and greenhouses in Ireland, Portugal, Netherlands and so on. The use of WSN technology in agriculture has positively impacted the environment and therefore the humanity, because the controlled irrigation and proper use of fertilizer can save drinking water levels and prevent water pollution. On the contrary, if irrigation and fertilization is performed in an uncontrollable fashion, it may have terrible and immediate consequences in underwater life.

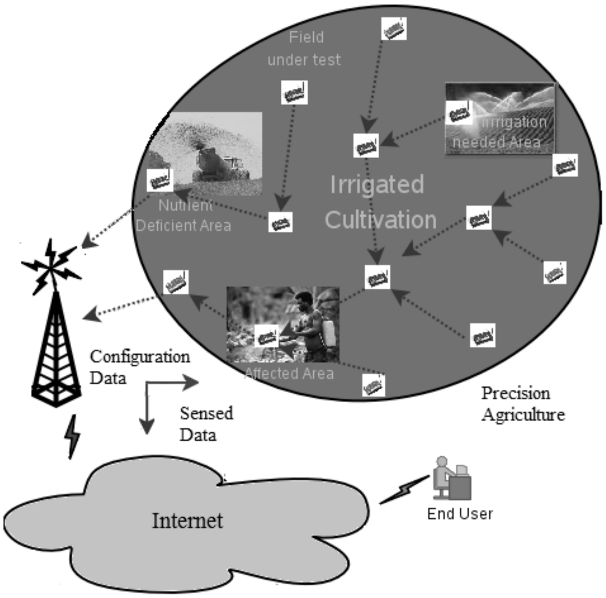

Figure 1. A typical WSN deployment for agricultural applications

The aforementioned applications provide technical information on their WSN deployments such as hardware and software issues, power and network issues, etc. [1-41]. Based on these data, in this paper we firstly categorize the existing applications relevant to WSN-based PA, summarizing the utilized WSN components, and secondly we provide with some generic guidelines on how to deploy a wireless sensor network for this type of applications.

To the best of our knowledge, limited work has been performed in the researched area. In [4] the writers present their experience in deploying a WSN on a rock glacier while afterwards they introduce guidelines based on this experience. There are no guides for specific field deployments such as, in our case, agricultural ones. Generally speaking, every application is an indirect guide since after every deployment the authors refer to the obtained results indicating advantages and disadvantages of their choices, followed by future suggestions. The above mentioned guide refers to the internal functionality of a WSN. On the other hand, our proposed guide refers to the deployment itself, providing practical and at the same time important guidelines. Based on these characteristics, the contribution of this paper lies on the fact of becoming a useful and practical guide for WSN installation companies in close interaction with farmers.

The remainder of the paper is organized as follows. Section II pinpoints existing WSN deployments and the components employed in each of them. Based on the collected data of Section II, Section III describes a generic deployment guide for WSNs aimed at supporting applications relevant to agriculture. Finally, conclusions are given in Section IV.

II. WSN COMPONENTS IN EXISTING APPLICATIONS

In this section, we record the components, both software and hardware, one needs to consider when deploying a WSN in applications relevant to PA [2] (the hardware components are depicted in Figure 2). The best way to gather the requirements for deploying a WSN system is to realize what actions the user would like the system to perform. In [5] for instance, the authors used ethnographic data of people working in a vineyard to conclude about the sensor network deployment.

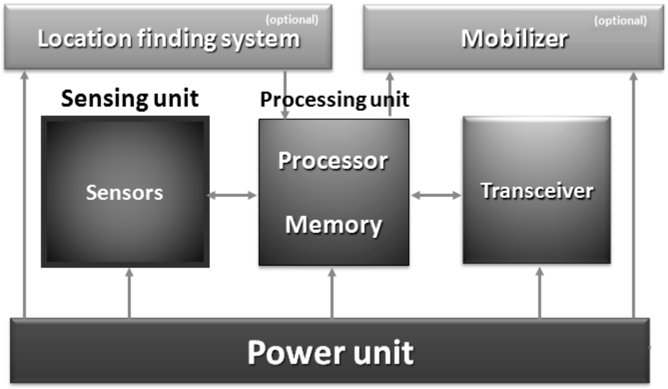

Figure 2. Basic components of a wireless sensor node

Starting with the general information about the deployments that were conducted in various fields and greenhouses, real time data collection and transmission is essential in this domain. Imagine a winemaker who has installed a WSN in his vineyard. If anything goes wrong and the data do not reach their destination, namely the winemaker's personal computer (PC) and the temperature will fall below the predetermined threshold, then probably this season's crop will be destroyed. Hence, in order to avoid this unfortunate event, special attention should be given to the data collection and transmission modules.

Choosing the parameters that need to be measured in order to have precision agriculture is also essential. Micrometeorological parameters like air temperature, air humidity, wind speed and direction, precipitation, as well as other weather data around and in the field of the deployment (either it is an open field or a greenhouse) are mostly collected. This means that the forecasts about a region where, for example, the vineyard is located do not relate with the climate in the field because fields with crops have always different climate, known as microclimate. The micrometeorological parameters outside the field are monitored with the installation of weather stations [6, 7]. Except of these parameters, there are in-field factors that have to be measured and usually are air temperature (T) and relative humidity (RH), soil T/moisture, salinity, etc. [8, 9, 10]. Of course the decision of what factors to monitor depends on the crop type.

Regarding the topology and architecture that is being used in WSN-based agricultural applications, the star single hop topology is commonly used with the nodes being organized in clusters to decrease the power consumption [11, 12]. Another topology used is the tree-based and the grid one both requiring multi hop communication [13, 14]. In other applications, the combination of the usual topologies was applied [15, 16].

Every deployment has its own needs imposed by the type of the monitored crop or plant or by other special application-related design requirements and of course by the budget that someone can afford. In addition, in almost every WSN deployment the node platform that is being used is that of the latest technology, at the time of purchase, so the choice of hardware and software is based on the aforementioned parameters. Starting with the node platform choice, many applications make use nodes from the Crossbow Berkeley which include MicaZ [8], Mica2 [17, 18, 19], TmoteSky by Shockfich [20] and others. Other platforms used from other companies are the Sensinode [21], TNOde, etc. [7]. Figure 3 presents the distribution of node platforms usage. In some cases, the scientists design their own sensor node from the scratch, because the existing ones do not cover their specific application requirements [16]. Most nodes are built around MSP430 and ATmega microcontrollers. The radio transceiver, the memory and the antenna are components included in the node platform, so upon purchasing a sensor node, these components are integrated and ready for use.

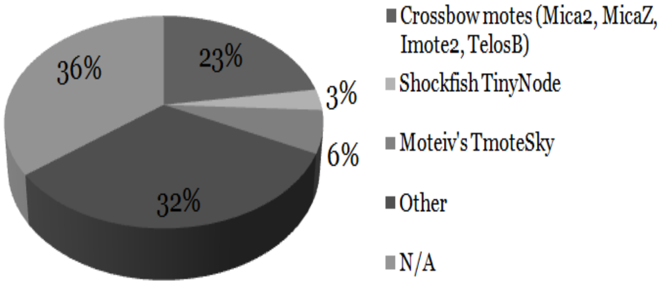

Figure 3. Most used node platforms

There is also the power unit, where the batteries are inserted. The batteries that are mostly used are Lithium, NiMH, and alkaline based on their chemistry and AA, AAA, D-cells and button cells based on their sizes. In most agricultural deployments, batteries are rechargeable using renewable energy in the form of solar panels.

In long-term deployments the above mentioned batteries while being rechargeable, however for efficient use of power and unattended and effective function of the WSN, there are protocols and algorithms that regulate the use of power in the system. These provide power management and saving techniques like duty cycles and sleep/wake up modes. There are also communication issues that specialized protocols and algorithms are used to deal with them. In some cases specialized algorithms, such as the Delta compression algorithm are being used for data packet size reduction [7]. Furthermore, the operating system (OS) that is being mostly used in agricultural WSN's is the TinyOS [8, 24] (Figure 4), an event-driven OS that has a very low memory foot print and it is written in nesC language [25].

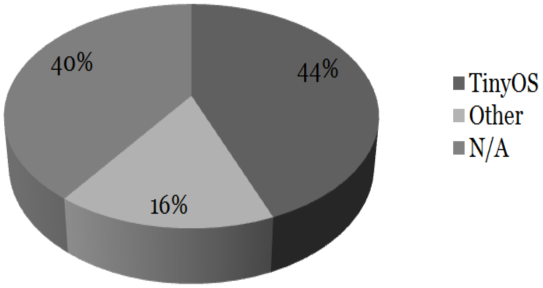

Figure 4. Mostly used Operating Systems (OSs)

In the agricultural deployments, the sensor nodes sensing and sending data is set to be time-driven, such as in [26, 27, 28, 29] in order to acquire a complete picture of the crop circumstances and act accordingly. There are other sensing strategies like event-driven, which are mostly used when monitoring phenomena such as volcanoes, earthquakes, etc., because in these cases the monitored subject is the event itself. However, in one case the event-driven strategy was used in agriculture [30]. Finally, the sensing task can be done on-demand based on the user/application requirements. The sensing intervals vary from one minute to one hour [31], although the agriculturists suggest that sensing measurements should be reported every five (5) minutes [24, 32].

As for the network issues, Radio Frequency (RF) is the most suitable form of wireless communication with the ZigBee protocol based on the IEEE 802.15.4 standard [8, 33, 34] to be the most common used standard. RF is used for node-to-node and node-to-base station (BS) short distant communication. It is less expensive and simplest than the Bluetooth technology, and all these characteristics made it widely used. Wi-Fi is another way of wireless, long distant communication usually between the BS and a remote PC server [35, 36]. Cellular communication is quite popular in agricultural WSNs, as the deployment areas in most cases, have the proper infrastructure GSM/GPRS [6, 37, 38]. In some deployments Ethernet and RS232 links are also being used [39, 40].

Finally yet importantly, is the cost and maintenance issue associated with the WSN deployment. In most deployments, the cost of the tiny sensor nodes is not publicly available. However, studies that present deployment economics refer to cost ranges from 20$ to 150$. The cost difference is due to different platforms and companies manufacturing the wireless nodes. This cost does not include sensor. In case of sensors integrated within the sensor node, then the cost is drastically reducing [1]. Most deployments do not mention the maintenance needs, since the sensor nodes in all deployments are installed in special enclosures for protection from the natural elements and the conditions under which they are deployed are considered normal in agricultural WSNs.

Some additional issues, but equally important with the aforementioned ones, are the following. Prior to deployments, there were always conducted test field deployments either in labs or under real outdoor conditions for evaluating the overall system performance. In addition, simulations were used for the same purpose. The evaluation of the WSN, which is a crucial issue, is done by using metrics like the RSSI (Received Signal Strength Indication), LQI (Link Quality Indicator) values as well as the PRR (Packet Reception Rate) and MDR (Message Delivery Rate) rates [41]. Generally, in most deployments, the deployed WSN managed to face the different problems and at the same time operated till the end, serving the purposes of the particular deployment. However, in one case the whole WSN system malfunctioned and did not manage to recover giving the opportunity to the team that worked over the project to give instructions for a deployment according to their experience [7].

III. BASIC GUIDELINES FOR DEPLOYING WSNS IN AGRICULTURE

The following section presents basic guidelines for deploying wireless sensor networks in agricultural applications. These guidelines resulted after surveying an exhaustive number of existing WSN-based agricultural applications. In discussing basic considerations relevant to the deployment, the guide covers issues such as type of sensors used, node platforms, OSs, transceivers, network topologies, installation and maintenance issues, etc. In order to showcase the usefulness of consulting the resulted guide, let us consider a representative agricultural monitoring scenario. Suppose a farmer needs to deploy a WSN system in his potato field. The field's size is about $100m^2$ and he needs to deploy it for the whole season (about 4 months). He also needs from the system not only to transmit the measured parameters to his PC but to realize irrigation. This means that besides the sensor nodes there must be actuator nodes as well (Table 1).

A. General issues

First of all someone who wants to develop a WSN has to consider the budget that is available for the deployment. There must be a decision whether the deployment will be in an open field or in a greenhouse. One must learn the requirements of the specific crop that want to be monitored or interested in monitoring the area to detect intruders such as rabbits. He or she should also decide whether the WSN will be reactive, that is will replace the person in the field in some critical tasks like irrigation and fertilization, or it will just send the gathered data to the BS. The owner will deal with the above tasks. In addition, due to the fact that the monitoring area is a changing one, there must be a consideration on the radio propagation issue, which will be reduced in more than half of the chosen radio ability. Moreover, the monitored parameters must be set from the beginning, in order to purchase the appropriate sensors.

B. Hardware and Sofrtware

One must choose the hardware/software and the types of sensors that will use. There are many commercial platforms available, as mentioned before. The Mica family from Crossbow Berkeley motes seems to be suitable for this kind of deployments. Also, in order to use more sensors, a sensor board must be adopted, which can allow up to 16 plugs for sensor attachment. The final and perhaps the most crusial option must be based on the power consumption of the node, power management and the balance between the radio coverage and transmitted power. For improving the radio coverage, external antennas can be used providing additional several hundreds of meters coverage.

Regarding the software issue, all the appropriate protocols and algorithms must be implemented for the efficient function of the WSN, including communication, routing, synchronization protocols and maybe compression algorithms. The operating system for the sensor nodes could be the TinyOS, which is commonly used and is compatible with many commercial platforms as well as with Mica family.

C. Communication issues - Topology

For a small deployment (e.g. 5-10 sensor nodes), a star topology with single hop communication can be implemented. Also, there must exist a BS and a PC based server where the monitored data will be displayed. However, this also depends on the size of the deployment area. For large deployments (over 20 sensor nodes), the single hop star topology is not recommended due to the increasing power consumption. So, a cluster tree based multi hop is appropriate. The communication of the nodes with the BS will be realized over radio frequency (RF), while the BS will connect with the PC using either Wi-Fi network or through radio modems for long distances. The BS will be placed near to the field deployment.

There may be a need to strengthen the signal, so some repeaters may need to deploy. This depends on the distance between the sensor network and the BS as well as the BS and the server. In addition, end users may connect directly with the server through Internet using web browsers as well as GUI tools for visualization of the data. Also, they may connect directly to the WSN. The connection between end users and server usually is established through GSM/GPRS or standard Ethernet depending on the communication infrastructure around the deployment area.

The coverage of the sensor nodes in agricultural WSN must be dense, i.e. 1 sensor node every 1 square meter ($1m^2$) [45]. Dense deployment serves to capture all the necessary measurements in order to have complete and reliable knowledge of the monitored area. Otherwise, there is no need to deploy a quite expensive system.

D. Sensor types and measured factors - Sensing issues

Some of the common and most critical measured factors in agricultural WSN are soil moisture, temperature, relative humidity, ambient light, wind speed and direction. In addition to these, there are other factors to measure such as leaf T and atmospheric pressure, which depends on the crop being monitored. The option of the sensor types such as Sensirion SHT75 or SHT71 for RH and T depends on factors related to sensor accuracy, resolution, range, power consumption, precision, cost, etc. Another issue of choosing sensors is that some platforms provide internal ones while others do not. For example, Mica2 motes do not provide any internal sensors, however they support the connection of sensor boards for sensor attach [43]. On the other hand, the TmoteSky nodes provide onboard humidity, T and light sensors [44]. This means that in case of Mica2 choice, separate sensors must be purchased and embedded through sensor boards, with the second choice some sensors are already integrated

The sensing and sending data packets must be time-based and the sensing time interval again depends on the crop type. However, according to existing deployments and to professional farmers, every 5 minutes is sufficient.

E. Power supply issues

Regarding power supply, it is evident that someone who is interested in setting a WSN would like it to last for the crop season, which depends on the nature of the crop itself. For example, potato crop needs about 3 to 4 months from sowing and cultivation to harvesting. This means that the system must withstand the period of these months with only one battery replacement or even better no replacement at all. In case of replacement they need not to be rechargeable. However, in case of using renewable energy sources such as solar panels, batteries must be rechargeable. Battery size depends on the platform used.

Regarding to battery chemistry such as Li-ion or lead-acid, the choice must be done according to its behavior under specific conditions. The most important issue however, is the implementation of power saving/management techniques with the use of appropriate protocols and algorithms.

F. Maintenance - Safety issues

Lastly, maintenance of the WSN system must be considered, because of the long-term nature of the deployment. The sensor nodes must be put into protective cases preventing them from moisture, mud, etc. These cases have ratings in form of IP00, which means no protection. The first digit means protection against solid objects, while the second means protection against liquids and every level has its definition. For example, in IP67, the “6” digit means total protection against dust and the “7” digit means protection against the effects of temporal immersion till 1m underwater [32, 42].

Table I summarizes the aforementioned guidelines and applies the guide in a representative PA scenario where the farmer deploys the WSN in order to perform irrigation. In this specific example, an open field of 50mx50m is assumed.

TABLE I. GUIDELINES TOWARDS DEPLOYING A WSN IN AGRICULTURAL APPLICATIONS

Component	***Description***
Monitoring object	Potatoes
Deployment duration	One crop season (about 4 months)
Area size	100m^2
Measured factors	-T -RH -Soil moisture *Please note that not every node will carry all the sensors
Topology/ Architecture	Tree-based multi hop communication. It includes the sensor nodes and the actuator ones, the sink nodes as gateways, a PC-based BS and the server for data storage
Node platform	Mica2 or TmoteSky or Micaz
Microcontroller	Depends on the platform
Radio transceiver	Depends on the platform
Memory size/type	Depends on the platform
Sensors	Either internal or external. i.e. -Hydra-Probe II for soil moisture. -MTS-420 for ambient light. -SensirionSHT11 for T & humidity. *Please also refer to subsection C for more details
Installation	The sensor nodes can be placed in grid to cover the entire area of 100m^2. The soil moisture sensor will be buried 20 or 40cm underground. The actuators will be placed somewhere in between the controlled sensor nodes, while the sink nodes outside and at the same time near to the field.
Sensing/ sending measurements	Time-based every 5min.
Number of nodes	Considering 1 sensor node per 1m^2, then 100 nodes or at least 80-90 nodes are needed. Ten of the nodes should act as actuators connected with sprinklers for irrigation. Two nodes should act as sink nodes and the rest as sensor nodes.
Protocols/Algorithms	Communication, routing, energy efficiency/management and synchronization protocols are needed.
Node OS	A popular candidate is the TinyOS system, which is supported by the proposed platforms.
Communication Network	RF from node-to-node and node-to-sink node. Wi-Fi between GW and BS. *Please note that the BS is in close distance with the WSN
Power supply	Rechargeable definitely. Use of solar panels for recharging. Reduced duty cycling and sleep/wake up mode. * Please also refer to section 2, paragraph 5 for more details
Waterproof case	IP67
Maintenance tasks	Due to long term operation there will be need to visit the monitored site.

IV. CONCLUSIONS

From the aforementioned analysis, it became apparent that the wireless sensor networking technology can become an integral part of the agricultural domain. Obviously, no unique solution for all the challenges exist, however the application of wireless sensors in land management can raise awareness of the effectiveness of new technologies in PA.

This paper reported a generic WSN guide in Precision Agriculture (PA), which was based on existing WSN deployments. These deployments were analyzed according to various issues such as power, network, maintenance, etc. to form an overall view on what components are used in existing applications. Thereafter, the aforementioned guide was derived from real life data. This guide is a practical and easy to read and use guide and is addressed to farmers who have not particular knowledge in this kind of technology and are willing to deploy a WSN. With this guide we aim to contribute as far as possible in adopting and deploying WSN technology in easy way by farmers.

In the future, the guide can be enriched to provide support for several other environmental monitoring applications such as air-water pollution, destruction phenomena (volcanoes, landslides, wild fires, etc.) and livestock-wild animal monitoring. Finally, another potential development could be to incorporate experiences from a real-life WSN deployment in a field or a greenhouse. This would in turn provide a framework for assessing and optimizing the proposed guide.

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