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Wireless Sensor Networks in environmental monitoring: existing applications and basic guidelines

Thesis by Mampentzidou Ioanna

Thessaloniki 2012

ΠΑΝΕΠΙΣΤΗΜΙΟ ΜΑΚΕΔΟΝΙΑΣ

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Wireless Sensor Networks in environmental monitoring: existing applications and basic guidelines

Thesis by Mampentzidou Ioanna [mis1010]

Supervisor: Prof. Anastasios A. Economides

Committee

Professor Anastasios A. Economides, Supervisor

Associate Professor Georgios Papadimitriou, Committee Member

Assistant Professor Petros Nikopolitidis, Committee Member

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Mampentzidou Ioanna

Abstract

The particular thesis investigates the real applications of Wireless Sensor Networks that have been implemented to date. The last decades the WSN technology has been adopted by more and more scientific fields for accurate and effective monitoring of climate phenomena like air pollution, destruction phenomena like landslides, etc. It has been widely used in agriculture as well as in horticulture for field monitoring. WSN is an emerging technology, which through the research in the labs and the real deployments has been proved to be a significant and valuable tool for scientists to explore another world which is behind the various environmental phenomena using tiny sensor nodes.

There is a reference on the basic components of a sensor node. In addition, the commonly used sensor node platforms are mentioned and the operating systems which are the most used and are supported by most of these platforms. Of course there are other platforms and OSs as well. According to existing applications, tables were developed for categorization of these projects in order to obtain and present a general view of the technology used in wireless sensor networks. These tables provide useful information about the conditions under which the deployments were conducted, about the hardware and the software is being used, etc. Based on this data, a basic guide is proposed for someone who is interested in deploying a WSN system. This guide has been developed for different types of deployments, which in this thesis is related to environmental ones such as monitoring wild animals and livestock, air-water pollution monitoring, vineyard monitoring and others.

Keywords

Wireless sensor networks, environmental sensor networks, sensor nodes, node platforms, operating systems, environmental phenomena monitoring, base stations, gateways, wireless communication, WSN topologies

CHAPTER 1

INTRODUCTION TO WIRELESS SENSOR NETWORKS – DESIGN ISSUES

1. Introduction

The curiosity of mankind for the natural environment and the environmental phenomena was the driving force that led him search and learn things that today are given for us. Thanks to this characteristic, nowadays we have the knowledge of various phenomena, thus giving us the opportunity, through detailed monitoring, to predict events and to prevent these of happening.

In the past, various physical parameters were measured by some analog mechanisms which at that time was very innovative, however too costly and not very efficient. In the last century the use of digital data loggers replaced the previous technology, being less expensive and more easy to use but still not efficient [Oliveira et al., 2011]. Recent technological advances led to the development of very small sensor devices with computational, data storage and communicational capabilities. These devices, which called wireless sensor nodes, when are deployed in an area (indoors or outdoors) form a Wireless Sensor Network (WSN).

The initial development of WSN was motivated by military applications such as enemy detection, battlefield surveillance, etc. [1]. Nowadays WSNs are used in many other fields, like agriculture, environmental monitoring of air-water pollution, greenhouse, oceans, volcanoes, forests, etc., health monitoring, structural monitoring and more. WSN is a very promising tool of monitoring events.

In the particular thesis, the issue under research is WSN in environmental monitoring, in which case the Wireless Sensor Network is called Environmental Sensor Network (ESN). ESN can be categorized broadly into two types of monitoring that is, indoor and outdoor [Oliveira et al., 2011]. Indoor monitoring includes building and offices. Outdoor monitoring refers to habitat monitoring [Polastre et al., 2003], flooding-landslide-earthquake detection [Basha et al., 2008 and Sheth et al., 2007], volcanic eruptions [Song et al., 2009 and Huang et al., 2011], traffic monitoring [Arora et al., 2005] and other.

Another categorization, referring to their behavior, could be into reactive and proactive. Reactive WSN means that the sensor nodes, upon measuring and sending the predetermined factors, take actions such as in agriculture whenever the soil moisture is below a predetermined threshold, then irrigation is starting for as long as needed. Proactive WSN means taking measurements and sending them to the centrals, where qualified personnel decide what measures to take.

With respect to the existence of other similar works and to the best of my knowledge, there is an article that refers to successful WSN deployment and a book with the title “Guide to Wireless Sensor Networks” by Sudip Misra and others. Reading the existing developed projects, one can conclude that every article is an indirect guide as it provides the results of the deployment and some guidelines for the future.

The major contribution of the guide being proposed in this thesis is to give generic instructions to the farmer, the environmentalist and the scientific community generally who are not necessarily related with WSN technology. In addition to the above, the goal of this guide is to contribute in making the WSN technology part of the user’s everyday working life, making it easier and more efficient.

Regarding the node platforms, the most common in use are those of Crossbow Berkeley-Motes, including the Mica family. Of course there are other platforms used like Fleck and TinyNode. On the other hand, the operating system used is TinyOS in most applications, but also ContikiOS and MantisOS. In chapter 2 there is a short reference to these operating systems and platforms.

1.1 Design issues

The idea behind this project was to detect real WSN deployments that have been developed and study them to make a categorization based on components used in every deployment. These components include general information about the deployment such as place of deployment, duration, area size, etc. Hardware parts such as node platform and its components, which are microcontroller, radio transceiver, memory size and type, types of sensors, number of sensors, installation and other issues. Regarding to software, the categorization was made based on protocols and algorithms used in every case and the operating system implemented in the sensor nodes. Network issues include the means of communication that is wireless, wired, satellite connection or cellular network. Also, the sensing of the measured parameters is classified into time-based, event-driven and requirement-based WSN as well as single hop or multi hop communication. The power management and supply is classified according to battery type, estimated lifetime, replacement issues and capacity as well as external power supply used for unattended WSN function and power saving/management techniques. Last but not least are the cost and maintenance issues regarding to WSN deployments.

Except the above categorization which is standard for every deployment category, there are some additional categorization information such as camera use and its components, robotic vehicles that are been used on water surface in water quality monitoring and its components. In some projects, there is risk assessment implementation that shows the possibility of deployed equipment damage (Low, Medium or High), like in case of wild animals monitoring, where the damage is unavoidable.

After every analysis of the technology being used in every type of deployment, basic guidelines derive based on these existing WSN deployments and tables including all the projects that have been used in this thesis as well as some indicative tables with the guidelines for brief update. In addition, there are some charts that include the total percentages of most used node platforms and OSs in every environmental WSN field. This data was chosen due to its availability in almost every project.

CHAPTER 2

AN OVERVIEW OF

WIRELESS SENSOR NETWORKS

2. Wireless Sensor Network

A WSN is, traditionally, consists of a few to dozens and in some cases thousands of sensor nodes, connected to one or more sensors, like in [Arora et al., 2005]. It also includes a Base Station (BS), which acts as gateway between the WSN and the end users.

Each sensor node is consisting of five main components, which are a microcontroller unit, a transceiver unit, a memory unit, a power unit and a sensor unit [2]. Each one of these components is determinant in designing a WSN for deployment.

- The **microcontroller unit** is in charge of the different tasks, data processing and the control of the other components in the node [3].
- Through the **transceiver unit** a sensor node performs its communication with other nodes and other parts of the WSN. It is the most power consumption unit.
- The **memory unit** is for temporal storage of the sensed data and can be RAM, ROM and their other memory types (SDRAM, SRAM, EPROM, etc.), flash or even external storage devices such as USB.
- The **power unit**, which is one of the critical components, is for node energy supply. Power can be stored in batteries (most common) rechargeable or not or in capacitors. For extra power supply and recharge, there can be used natural sources such as solar power in forms of photovoltaic panels and cells, wind power with turbines, kinetic energy from water, etc.
- Last but not least is the **sensor unit,** which includes one or more different types of sensors for parameter measurements. Sensors measure physical parameters like Temperature (T), Relative Humidity (RH), soil moisture, etc., chemical like carbon dioxide (CO_2), methane (CO_4), carbon monoxide (CO), etc. and many other [Yoo et al., 2006].

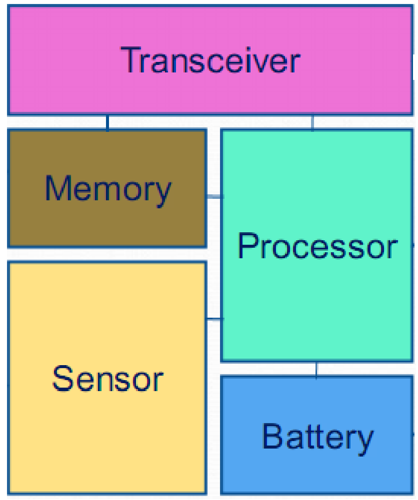

Figure 1: Basic sensor node architecture

The usual topologies in WSN are star, tree-based and mesh topology in single or multi hop communication.

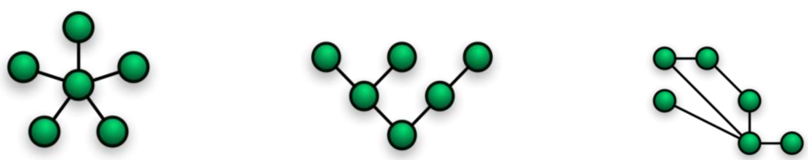

Figure 2: WSN topologies

In star topology every node in the WSN is connected directly to its sink node only. While being simple in its implementation, it is not recommended in deployments with many sensor nodes and large distances between nodes and the sink. In case of link failure between one node and the sink there is no alternative route of communication [Argyriou 2010].

Tree-based topology is an ideal option for WSNs with large distances with the sink node it is the opposite of star. Of course it has its own disadvantages, for example the nodes that are close to sink are being over headed so collisions and delays are unavoidable. In addition, if a node fails to operate for an unknown reason, then the communication with its children will be off [Argyriou 2010].

In mesh topology every node is connected with maximum number of other nodes. It is a specification of a fully mesh topology and with the appropriate routing algorithms, it ensures the recovery of the network from breakdowns [Argyriou 2010].

Below there is reference in some of the most known node platforms and operating systems (OSs).

2.1 Sensor node platforms

In this section there is a reference in common used node platforms, as revealed by the existing WSN applications. These are of Crossbow Berkeley motes like the Mica family some of which are referred below, TinyNode of Shockfish and Fleck3 mote which is Australian.

Mica2 mote: third generation of Berkeley mote, manufactured by Crossbow[1] [Hu et al., 2009]. The Mica2 motes don't include sensors on the platform board rather than the sensors can be attached to it using external sensor board like MDA300. They are available since 2003 and one of its main characteristics are the 8-bit Atmega 128L at 8MHz MCU, Multi-Channel Radio Transceiver at 433, 868/916, or 310 MHz the range of which is about 150-300m (500-1000ft), the 128KB of program memory and additional 512KB of flash with the use of 2AA batteries and supports TinyOS operating system [4].

[1] http://www.xbow.com

Figure 3: Mica2 mote

Mica2Dot mote: the Mica2Dot is a repackaged Mica2 mote, a production of Crossbow [Szewczyk et al., 2004]. Its size of the order of mm, diameter 25 and height 6, makes it an attractive solution in monitoring small habitats e.g. bird burrows. Its MCU, radio and storage capacity is the same as of Mica2 mote. TinyOS is supported from Mica2Dot while it is powered by 3V coin cell [4].

Figure 4: Mica2Dot mote

MicaZ mote: it is a new version of Mica2 mote and supports the use of IEEE 802.15.4/ZigBee compliant radio transceiver and the data rate is 250kbps. The memory and the microprocessor are the same with the Mica2 mote. The outdoor range of the radio is 75-100m while indoors is 20-30m [4].

Figure 5: MicaZ mote

Fleck™ 3node: is one of the members of the Fleck family, which also includes the Fleck 1 & 2 and the latest ones, Fleck3B and Fleck nano. The microcontroller used is an Atmega 128, combined with 1Mb flash memory. The radio is Nordic905 at 915MHz. It also includes an on-board temperature sensor and is supported by TinyOS as well [5].

Figure 6: Fleck3 node

TinyNode mote: is a sensor mote manufactured by Shockfish. It has long communication range, up to 200m outdoors and a low power consumption. TinyNode includes a 16-bit MSP430 microcontroller at 8MHz, a Semtech XE1205 radio transceiver at 868MHz. It integrates ROM, RAM and flash memory of 48KB, 10KB and 512KB respectively. TinyOS is supported by TinyNode [Barrenetxea et al., 2008 and Talzi et al., 2007].

Figure 7: TinyNode mote

2.2 Operating Systems in WSN

The operating systems (OS) are classified according to a framework for WSN OSs [Mallikarjuna et al. 2007]. This classification is based on architecture, execution model, reprogramming scheduling and power management. Below are mentioned some of the most used OSs according to the deployments.

TinyOS[2]: belongs to monolithic architecture and is implemented in nesC language. It is an event driven operating system with low memory foot print. The communication is implemented with the use of Active Messages (AM), which has 36bytes size and a 1byte handler ID. Because it is event driven model, it has disadvantages such as low programming flexibility [Mallikarjuna et al. 2007]. Regarding to reprogramming, TinyOS uses XNP dissemination protocol as well as is supported by Deluge and MOAP protocols. Due to having monolithic architecture reprogramming causes high communication overhead. It provides API for proper conserving and managing of power as it manages the radio and the MCU [Mallikarjuna et al. 2007]. Simulations for TinyOS are implemented in TOSSIM, the code of which can be used in simulation as much as in testbed deployments [Mallikarjuna et al. 2007].

ContikiOS[3]: its architecture is modular or component and it uses a hybrid model, which means that combines event-based and thread-based models. Reprogramming in this case does not affects the entire system but only the required application service [Mallikarjuna et al. 2007]. Contiki does not support power management mechanisms however it allows the implementation of these. In addition, it does not support proper memory management

[2] http://www.tinyos.net
[3] http://sics.se/~adam/contiki

mechanisms, which probably causes an overhead in reprogramming. Its advanced simulation environment is Cooja [Mallikarjuna et al. 2007].

MantisOS[4]: its architecture is same like the previous one, that is modular, while it is a thread-based model something that provides flexibility in writing applications. However, its disadvantage lies in the fact of overheads of context switching and memory allocating in each thread which is important in poor resource systems such as WSNs are [Mallikarjuna et al. 2007]. The MantisOS uses power management techniques, which includes sleep wake mode for the MCU. It gives the opportunity to the developer to test the written code on virtual as well as on original sensor nodes to [Mallikarjuna et al. 2007].

[4] http://mantis.cs.colorado.edu

CHAPTER 3

WSN APPLICATIONS IN AGRICULTURE

GUIDE FOR WSN DEPLOYMENT

3. WSN in Precision Agriculture

In the past few years the Agriculture domain has incorporated the WSN technology, thus 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 real needs of irrigation and fertilizer as well as all the phases from sowing to and harvesting. All these can realize using new technology such as satellite imagery, geospatial tools and WSN. Horticulture is also enjoying WSN technology as well.

There are enough WSN applications so far in PA, 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 [López Riquelme et al., 2009, Matese et al., 2009 and Garcia-Sanchez et al., 2011]. The use of WSN technology in agriculture has positive impact on the environment and therefore on people, because the controlled irrigation and proper use of fertilizer, that is whenever it is unavoidable, saves drinking water levels and prevents water pollution, which in turn has immediate and terrible consequences in underwater life.

In PA WSNs different types of nodes are being used. There are identification nodes, which are used for intruder identification, e.g. someone who wants to install these nodes in his farm for monitoring intruders, like some animals that may destroy the crops, and the detection nodes which detect the intruder using cameras.

In the following section there is a reference on the WSN components, including hardware and software issues as much as power supply and costs, that have been used in existing agricultural deployments. At the end of it, there is a guide for WSN deployment.

3.1 Agricultural monitoring deployments

Starting with the general information about the deployments, which have been conducted in various places worldwide, in fields and in greenhouses, **real time** data is essential in this domain. Imagine a winemaker who has installed a WSN in his vineyard. If anything will go wrong and the data will not reach its destination which is the winemaker's PC and the temperature will fall below predetermined threshold, then probably this season's crop will be destroyed. We can only imagine the cost of this unfortunate event.

The factors that have been measured in PA are micrometeorological parameters like air temperature (T), air humidity, wind speed & direction, precipitation, etc., which means the weather data around and in the field of deployment either it is an open field or a greenhouse. This means that, the forecasts about a region where for e.g. a vineyard is located do not relate with it because fields with crops have always different climate, which called microclimate. The micrometeorological parameters are monitored with the installation of weather stations. Except these parameters, there are in-field factors that have to be measured and usually are air T & relative humidity (RH), soil temperature, moisture and salinity (Appendix A).

Regarding the topology and architecture used in agricultural WSNs, star single hop topology with the nodes organized in clusters is the most usual, because often the number of nodes is two-digit, large enough to increase the power consumption. Another topology used is tree-based and grid with multi hop communication.

Every deployment has its own needs based on monitored crop or plant and factors as well as its special requirements and of course the budget that someone can afford. Also, in almost every WSN deployment the node platform that is used is that of the latest technology, at the time of purchase, so the choice of hardware and software is based on aforementioned parameters. Starting with the node platform choice, many applications make use of the ones of Crossbow family, which include MicaZ [Ayday and Safac 2009], Mica2 [Vellidis et al., 2007, Beckwith et al., 2004, Giacomin and Vasconcelos 2008 and Bencini et al.], Mica2Dot [Goense et al., 2005], Iris, TmoteSky [Tseng et al., 2008] and others. In other cases there were other platforms used like Sensinode, TNOde, LPC2148F [Aquino-Santos et al., 2011], etc. In some cases, the scientists design their own sensor node, because the existing ones doesn't cover their specific requirements. In Figure 8 there is the percentage of the different platforms used in Agricultural deployments. 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, it is integrated and ready for use. There is also the power unit, where the batteries are inserted. The batteries that are used in sensor nodes usually are Lithium, NiMH, lead-acid and alkaline based on their chemistry and AA, AAA, D-cells and button cells based on their sizes. In most of the cases, batteries are rechargeable using renewable energy in forms of solar panels in most agricultural deployments.

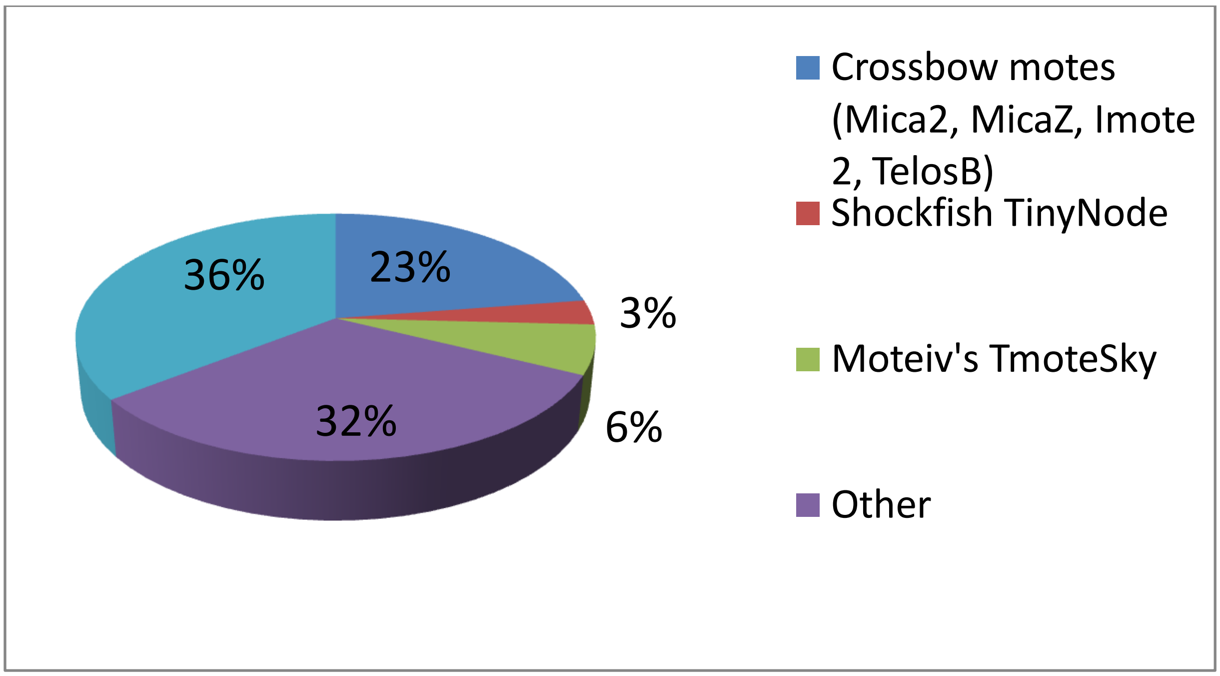

Figure 8: Most used node platforms

In long term deployments the above mentioned batteries, while 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, providing power management and saving techniques like duty cycles and sleep/wake up modes. There are also routing, communication and other issues that specialized protocols and algorithms are used for regarding the software components. In some cases there was use of compression algorithms like Delta, for data packet size reduction. The operating system that is used in agricultural WSN's is the TinyOS (Figure 9), in most of the cases, which is an event-driven operating system, it has a very low memory foot print and it is written in nesC language [Mallikarjuna et al. 2007].

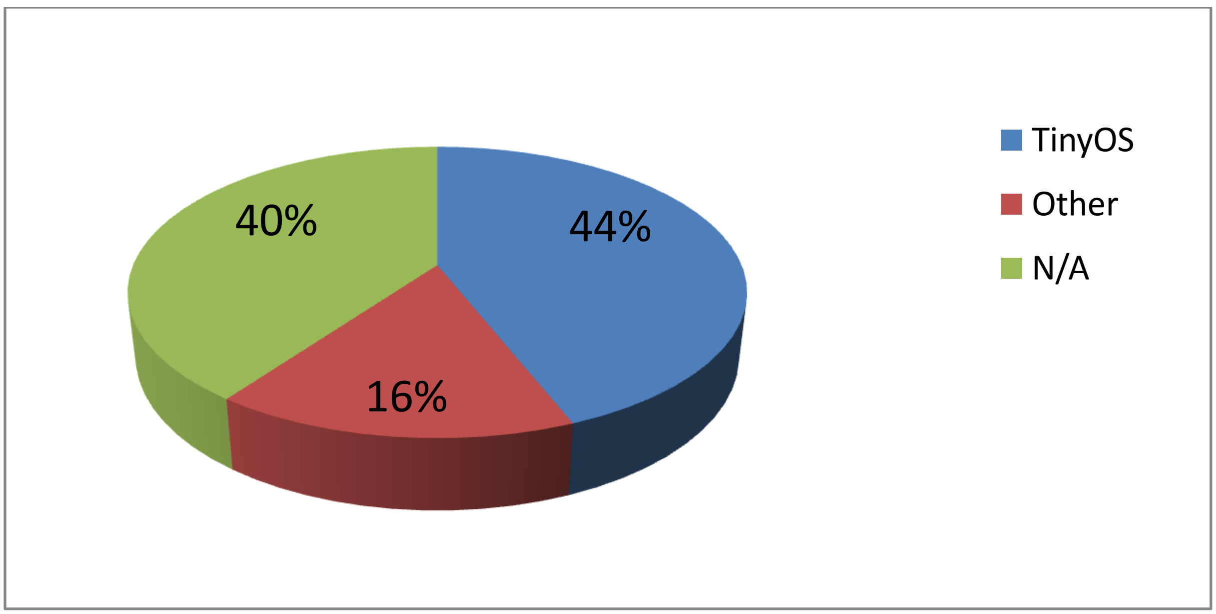

Figure 9: Most used OSs

In the agricultural deployments, the sensor nodes sensing and sending data is set to be time-based in order to acquire total image of the crop circumstances and to be able to act accordingly. There are other sensing strategies like event-driven, which mostly used when monitoring various phenomena (volcanoes, earthquakes, etc.) because in these cases the monitored subject is the event itself, and requirement-based, which is basically based on user requirements, that is on demand. The sensing intervals vary from every one minute to every hour, although usually it is every 5 minutes, which is set from the agriculturists as appropriate.

As for the network issue, Radio Frequency (RF) is the most suitable form of wireless communication in the WSN with ZigBee, based on IEEE 802.15.4, as the most common used standard. RF are used from node-to-node and from node-to-BS or gateway, that is for short distant communication. It is less expensive and simplest than Bluetooth technology, characteristics that made it widely used. Wi-Fi is another way of wireless, long distant communication usually between the BS and a remote PC server. Cellular communication is quite popular in agricultural WSNs, as the deployment areas in most of the cases, have the proper infrastructure GSM/GPRS. In some deployments there was use of Ethernet and RS232 links.

Last but not least is the issue of WSN's cost and maintenance. Generally speaking, the cost of the tiny sensor nodes most of the times in not available but from other deployments that it is available, starts from $150 and it is ranging, in my opinion, due to different platforms and companies that manufacture it. This price does not include sensors, which are relatively expensive, at about $300 [López Riquelme et al., 2009]. In case of sensors integrated within the sensor node, then the cost is drastically reducing [López Riquelme et al., 2009]. There were no mentioning on maintenance needs, as the sensor nodes in all deployments are installed in special enclosures for protection from the elements and the conditions under which nodes are deployed are considered normal in agricultural WSNs.

Some additional issues but equally important with the aforementioned are discussed here. Prior to deployments, there was always conducted a test field deployment in lab or under real conditions outdoors for evaluating the overall system performance. In addition, simulations were used for the same purpose. The evaluation of the WSN, which is crucial issue, is done using two metrics: the RSSI (Received Signal Strength Indication) values and the LQI (Link Quality Indicator) as well as the PRR (Packet Reception Rate). Generally in most of the cases, the deployed WSN managed to face the different problems and function till the end, serving the purposes of the particular deployment. However, in one case the whole WSN system malfunctioned and didn't manage to recover but the team that worked over this project learned many useful lessons that shared with other scientists as well [Kerkez et al.].

3.2 Agricultural monitoring guide

The following section is a basic guide for WSN deployment in the domain of Agriculture, based on existing applications, which can be found in form of Tables, in Appendix A.

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 a greenhouse. Then one must learn the requirements of the specific crop that want to be monitored or interested in monitoring the area for security reasons and of course if this WSN will be reactive, that is will replace the person in the field in some critical tasks like irrigation and fertilization, or it will be a proactive, which means sensing and sending the monitored parameters to the owner, who will deal with the above tasks. Also, due to increased foliage, one must consider that the radio propagation will be reduced in more than half of the chosen radio ability. In addition, the monitored parameters must be set from the beginning, in order to purchase the appropriate sensors.

After this step one must choose the hardware and the types of sensor that will use. There are many commercial platforms that are available, as mentioned before. The Mica family, from Crossbow Berkeley motes, are suitable for this kind of deployment. Also for more sensors to use, a sensor board must be adopted, which can allow up to16 plugs for sensor attachment. The final option must be based on the power consumption of the node, power management and the balance between the radio coverage and transmitted power [Bencini et al.]. For improving the radio coverage, there are external antennas that can be used, providing additional several hundreds of meters coverage.

For a small deployment, star topology with single hop communication can be implemented, consisting of 5-10 sensor nodes, of course it depends on the size of the deployment area, a BS and a PC based server where the monitored data will be displayed. The communication of the nodes with the BS will be over RF, while the BS will connect with the PC using either Wi-Fi network or through radio modems for long distance for the BS, which will be near to the field deployment, while the PC is often located in a remote office for example. There can 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 with web browsers and use 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, again it depends on the communication infrastructure around the deployment area. Generally speaking, the coverage of the sensor nodes in agricultural WSN must be dense to capture all the necessary measurements in order to have integrated and reliable knowledge of the monitored area, otherwise there is no need to deploy a quite expensive system.

On the other hand, for large heterogeneous (heterogeneous means combination of sensor nodes with different abilities, sensors achieving balance in the performance and the cost of WSN) deployment, that is over 20 nodes, hierarchical multi hop topology is more suited [Tseng et al., 2008]. There will be different types of nodes, except for sensor nodes also aggregator nodes, repeaters, which are used for data aggregation to Gateway (GW) or the BS and other nodes in order to combine successfully all these components.

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 very common in use and is compatible with enough commercial platforms and with Mica family as well.

The usual measured factors in agricultural WSN are soil moisture, temperature, relative humidity and ambient light. The option of the company from which the sensors will be purchased does not affect the WSN, so it may be based on the cost. The sensing and sending data packets must be time-based and the sensing time intervals depend on the crops under monitored. However, according to existing deployments, every 5 minutes is sufficient.

Regarding the issue of power supply, I can imagine that someone who is interested in setting a WSN would like it to last all 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 harvest, this means that the system must withstand the period of those months with only one battery replacement or even better no replacement at all. The batteries can be one of mentioned in previous section, in case of replacement they need not to be re chargeable, however in case of using e.g. solar panels batteries must be rechargeable. The most important issue although, is the implementation of power saving/management techniques and appropriate protocols and algorithms.

Lastly, maintenance of the WSN system must be considered, because of 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 forms 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 e.g. IP67, the “6” digit means total protection against dust and the “7” digit means protection against the effects of temporal immersion till 1m underwater [6].

Below are indicative tables, which include the mentioned guidelines. We consider an example of a $10m^2$ area size with potatoes.

Deployment duration	Area size	Measured factors	Topology/Architecture	Node platform	Microcontroller	Radio transceiver	Memory size/type	Sensors	Installation
One crop season (let us consider about 4 months)	$10m^2$ (will be considered for the example)	-T -RH -Soil moisture -Light intensity (as standard sensors) Note that not every node will include all the sensors	Let us consider a simple multi hop grid topology, including sensor nodes and actuator nodes, a sink node as gateway and a BS PC-based, including the server	Mica2 or TmoteSky, or Micaz or other	Depends on platform	Depends on platform	Depends platform	Maybe internal of the platform or external For example: - Hydra-Probe II for soil moisture - MTS-4 for ambie light - Sensiri SHT11 for & humidity	The sensor nodes must be placed in grid to cover the entire area of $10m^2$. The soil moisture sensor will be buried 20 or 40cm underground. The actuator will be placed somewhere in the middle of the field, while the GW out of the field

Table 1: Agricultural WSN guide

Sensing & sending measurements	No of nodes	Protocols/Algorithms	Node OS	Network	Power supply	Waterproof case	Maintenance tasks
Time-based every 5min	Considering 1 sensor node in about $1m^2$ then about 10 nodes is sufficient, from which 8 are sensor nodes, 1 is actuator connected with a sprinkler for irrigation and 1 sink node	Communication, routing, synchronization, energy efficiency and any other is needed	Probably TinyOS	RF from node-to-node and node-to-GW Wi-Fi between GW and BS	Rechargeable definitely, one of aforementioned Use of solar panel, is appropriate Reduced duty cycling and/or sleep/wake up mode	YES	Due to long term operation there will be need to visit the monitored site

Table 2: Agricultural WSN guide (continues**)**

CHAPTER 4

WSN IN MONITORING NATURAL ENVIRONMENT

GUIDE FOR WSN DEPLOYMENT

4. WSNs in Natural environment

The natural environment has always been drawing scientists' attention for research and study. With the use of wireless sensor networks, they have a powerful tool for deeper understanding of the functionality of microenvironments of the nature, something that will give the bigger picture.

Due to its ease of deployment and its use in various projects WSN technology has become attractive for environmental monitoring [Yang et al., 2009]. Issues such as canopy closure, permafrost and glacier study and many other, are now realizable thanks to these tiny devices. As we all know and many of us live it, the environmental changes the last decades are increasing covering every corner of the world. From ice melting in Antarctica and the flooding phenomena all around the world to endangered species of flora and fauna. WSN technology may give us answers about these phenomena, scientists may make predictions to be able to "see" the future and hence give solutions if possible to deal with.

The number of deployments is not high, due to the relatively novel nature of the WSN and its cost, however it has dropped significantly the last years and more and more projects have been started, which are long term, for years, ongoing deployments like in [Huang et al., 2011].

Below there is a presentation of the usual components of environmental WSNs that have been used in existing deployments.

4.1 Environmental monitoring in existing deployments

The existing deployments in environmental WSNs have been set to monitor mostly forested environments head water catchments, microclimate around trees, which affects its existence, permafrost areas and glaciers. According to these, the deployed areas are always large, measured in hectares (ha) and the landscape features like elevation, is sometimes some thousands meters above. These areas most of times of the year are unreachable so the WSN must be robust and power efficient to withstand under harsh conditions.

The measured factors, except for soil moisture & temperature, air humidity & temperature, include many new parameters compared to agriculture. Here, the sensor nodes in some cases like rock glaciers [Barrenetxea et al., 2008 and Talzi et al., 2007] and glaciers [Padhy et al., 2005] must be placed inside rocks or buried under ice (Appendix B). So the measured factors refer to pressure from the ice to define their movements, orientation of the glacier and other parameters like solar radiation, surface temperature, etc. A very important measurement is also the WSN health, which is proved with status messages, including battery voltage, link quality, etc.

The topologies usually used in these deployments, based on the existing ones are mesh, hierarchical, tiered and tree based topologies. These tiered topologies are often self supported because in failure cases not to affect the other tiers. As it was mentioned, monitoring natural environments usually involves harsh conditions.

As for the hardware choices, Mica family is again the usual choice of several deployments as well as TinyNode platforms by Shockfish (Figure 10), which provide the lowest-power state of the art module and full support of the TinyOS [Yoo et al., 2007]. GPS is also used for localization of the nodes and for local and global time stamp of the data packets. The controller, the radio, the antenna and the memory are integrated in every platform, so it depends on the platform choice, as it was already mentioned. The installation of the sensor nodes is made by the scientists in organized and strategic way and even in some cases, the team members of the project, particularly of "Permafrost" [Talzi et al., 2007 and Beutel et al., 2009], in order to avoid risk when working in the field which is Swiss Alps, undertake regular alpine safety training courses [Beutel et al., 2009]. Weather proof enclosure is a must in these environments, as in many cases, the boxes that contain the sensor nodes are IP67 rating at least and in some other cases it is made of polyester.

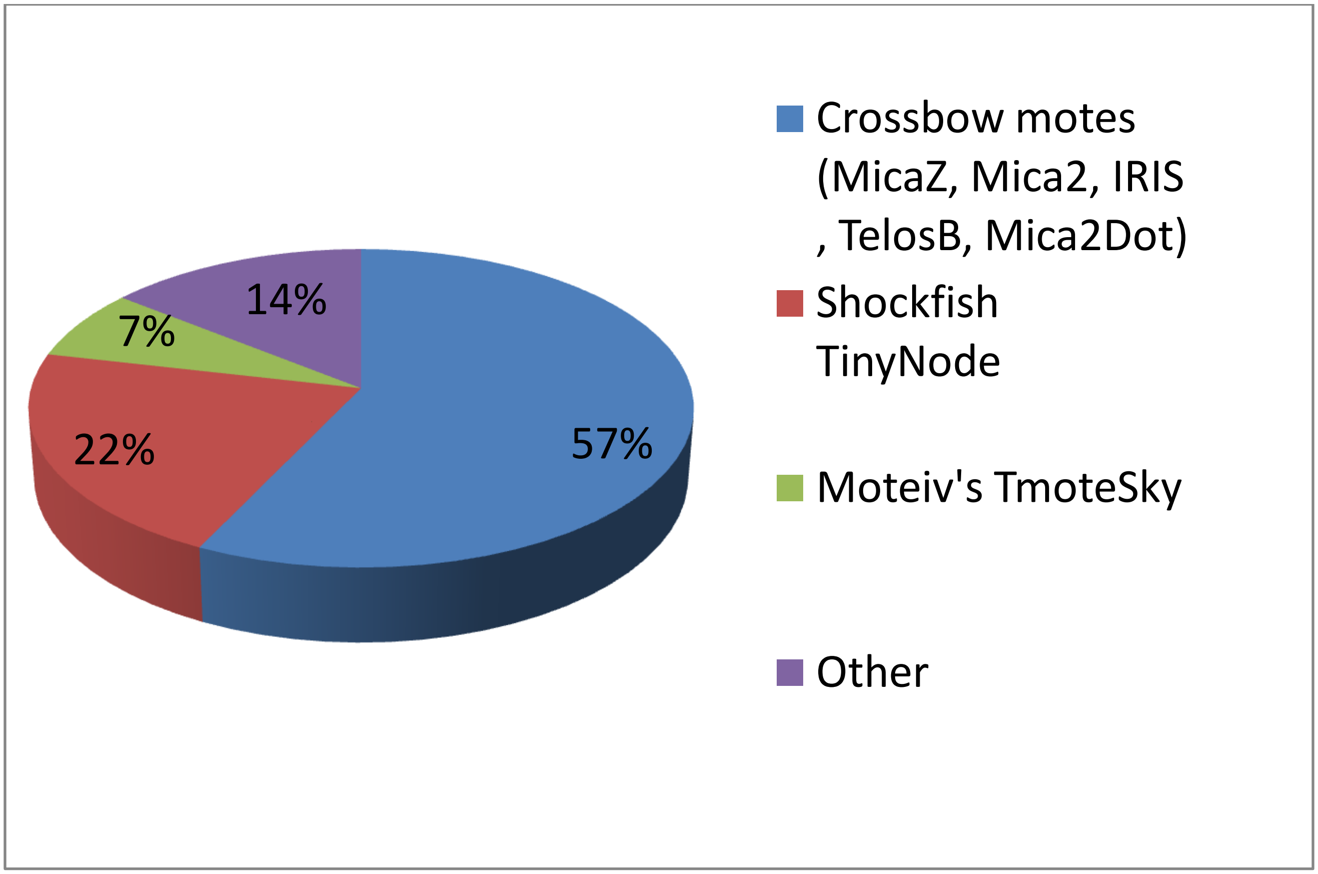

Figure 10: Node platforms

The measured parameters are sensed from the sensor nodes in predetermined, fixed intervals, so the WSN is time-based like in agriculture. There are some deployments were the sensing is reactive depending on e.g. rain events, which means that when a node will sense soil moisture over a predetermined threshold, it will start to sense more frequently, that is from hours to minutes [Cardell-Oliver et al., 2005]. In these cases, one can say that the network is time-based and event-driven. The sensing time is again varies from minutes to hours.

The software used in ESN is TinyOS (Figure 11), which dominates over other operating systems. Among the usual and necessary protocols and algorithms used are CTP (Collection Tree Protocol), Dozer multi hop, STP (Spanning Tree Protocol), filtering and compression algorithms.

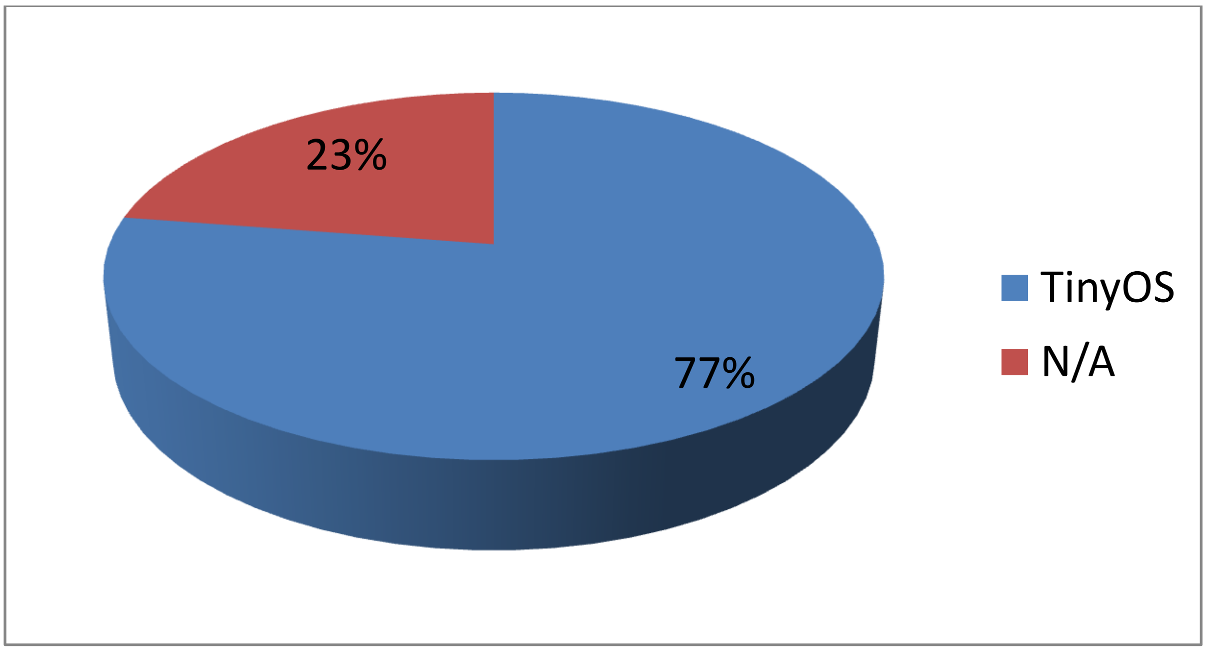

Figure 11: OSs used

Regarding the network issues, RF using 802.15.4 and ZigBee, is again the most popular way of communication and data transmission from node to node and node to GW or BS. GSM/GPRS connections are used for backup in case of other connection failures but also as primary communication for BS and remote connection from the server for reconfiguration issues WSN control. In addition, serial connections using RS232 ports between the GW and BS is implemented as well as Ethernet and ISDN dial up.

Different types and sizes of batteries are used for power supply but in most cases with high capacity for obvious reasons. The use of solar cells and panels is often because the batteries are rechargeable and need to withstand through heavy weather conditions and long term deployment. Of course, the implementation of different power management techniques is essential and include sleep-wake up cycle, duty cycling and aggregation & compression techniques. Using these techniques the WSNs manage to function for months.

It is fact that for so long term duration of deployments and given the harsh conditions under which sensor nodes are installed, there must be some maintenance tasks several times a year. So there is a cost of sending team for these tasks, except for the cost of purchasing the WSN components. As it was mentioned above, another cost is the regular safety training of the team members working in these areas.

4.2 Environmental monitoring guide

Depending on the deployment site, there are variations in the area size but in ESN, generally, the monitored areas are large in space. Proper evaluation of the area and the weather conditions must be done, meaning the place where the nodes will be installed, the distance between the nodes must be determined, and between nodes and the sink node or gateway and the remote BS server. As regarding to the conditions, all the possible weather data must be known for the period of duration of the WSN. In addition, in some environments like glaciers, special surveys must be done for determine e.g. the sub-glacial circumstances, which include geophysical anomalies for example the existence of a river [Padhy et al., 2005].

After these assessments, one has to decide what parameters want to measure. This decision is based on the environment where the WSN system will be deployed. For example, if the monitored environment will be a head water catchment, the probable parameters for measurement, among others, will be soil moisture and temperature, relative humidity (RH). After the parameters the topology must be figure out. In the existing deployments, as mentioned above, the most common topologies are tiered/hierarchical, mesh in multi hop communication and transmission. The topology decision will be based on the number of the sensor nodes will be deployed, on the energy constraints, the duration and the cost. So for long term and relatively large WSN deployment, I believe that the tiered one is the mist suitable, for it offers flexibility and balance with the appropriate software of course.

The hardware choice is again based on the aforementioned constraints. However, according to the existing deployments the common used platforms are of Crossbow Berkeley motes and the TinyNode of Shockfish which is proved to withstand the harsh environments. The coverage of sensor nodes in the area, here depends on the environment monitored, which means that when monitoring glaciers or permafrost it doesn’t have to be necessary large deployment or dense, maybe only for communication and transmission reasons, because the variations in these kind of environments are in distance. Of course the more sensor nodes, the larger area coverage but this is not something that will affect the obtained results. On the other hand, if someone is interested in setting up a WSN to monitor the canopy closure[5] estimation or the microclimate of a forest or more specific of some type of a tree like in [Tolle et al., 2005], then the nodes must be more in number and densely placed. Lastly, the nodes must be put in protective cases. In addition, a GPS receiver is needed for nodes localization and data timestamping.

The sensing interval is strongly depended on the constraints mentioned above and the environment under monitoring. In addition, the sensing can be reactive, if someone wants to measure the soil properties before and after natural phenomena, like when raining the sensing could be more frequent and then adjust to initial state. Also, the data in ESN does not to be necessarily real time, so the measured data can be stored in temporarily in the motes and the transmission can be done once every 10 to 15min or even once a day, which reduces the energy consumption. The transmission tasks are the most hungry power tasks.

The software depends on the deployment nature, although there are standard protocols and algorithms that are essential for the proper function of the WSN. Regarding the OS, the TinyOS can be used that is supported by the most number of platforms and generally, is effective OS.

As for the network that can be used, there are many ways for data communication and transmission. RF is the standard wireless for the motes as well as WLAN, while cellular network can be used for remote user connection with the server and the WSN itself, if there is appropriate infrastructure otherwise through Ethernet. Also the gateway or the sink node can connect to the BS, that can be a laptop or a PC, serially.

The power supply is the most important issue for the WSN survival through difficult weather conditions and the long term deployment nature. One good solution for battery choice are non rechargeable Li-SOC12, which with the proper modification in the source code for automatic power management and sleep wake cycle can achieve a lifetime of 4-5 years. Also, couple of 3.6V Lithium Thionyl Chloride cells rechargeable by two solar panels and sleep wake

[5] Canopy closure: “the percentage of ground area vertically shaded by overhead foliage” [29].

cycle can achieve, theoretically, 10 years lifetime! Compression of data, if the sensing and the transmission are frequent as well as duty cycling is also an effective way for energy consumption reduction.

Considering the cost issue in ESN, maybe is higher than in other applications mostly due to the fact that the sensor nodes either have to be attached to rocks or trees, which means extra equipment or to be places on ice surface, which needs tripod to attach the sensor node, the panel and the antennas on it. Also the WSN must be even more robust, self recovering, able to cover large distances and able to keep data temporally in node's memory due to the fact that the nearest BS server will be kilometers away from the deployment site, which means strong MCU, radio transceiver, requirements for more memory size and even external, something that cost. Maintenance is also part of the cost.

Below are comprehensive tables that include the information mentioned above.

Deployment duration	**Area size**	**Measured factors**	**Topology/Architecture**	**Node platform**	**Microcontroller**	**Radio transceiver**	**Memory size/type**	**Sensors**	**Installation**
Depends on the deployment site	Depends on the deployment site	-Air T -RH -Soil moisture & T -Solar radiation And many other depending on the monitored site Note that not every node will include all the sensors	Mostly tiered – hierarchical multi hop topology	Mica family and TinyNode from Shockfish	Depends on platform	Depends on platform	Depends platform	Maybe internal of the platform or external	The sensor nodes will placed in strategic places. Depends on the deployment site e.g. if the site is a mountain monitoring the rocks then they must be attached on the rocks

Table 3: Environmental WSN guide

Sensing & sending measurements	No of nodes	Protocols/Algorithms	Node OS	Network	Power supply	Waterproof case	Maintenance tasks
Time-based every 5-10min sensing and data transmission every 15min	Depends on the deployment site and the monitored object. Dense deployment if it is for microenvironment monitoring	Communication, routing, synchronization, energy efficiency and any other is needed	TinyOS	RF or WLAN from node-to-node and node-to-GW Wi-Fi, between GW and BS For remote connection to the server trough GSM/GPRS or Ethernet	Li-SOC12 with modifications in the source code Couple of 3.6V Lithium Thionyl Chloride cells rechargeable, by two solar panels and sleep wake cycle	YES	Due to long term operation and the harsh conditions there will be need to visit the monitored site several times

Table 4: Environmental WSN guide (continues**)**

CHAPTER 5

WSN IN AIR-WATER POLLUTION MONITORING

GUIDE FOR WSN DEPLOYMENT

5. Air-Water pollution

The air and water pollution phenomenon is an issue of major concern in the last decades. Mankind has contributed to this phenomenon from Industrial Revolution until today. Unfortunately, there are more and more outbreaks of the existence and increase of air-water pollution, which is demonstrated with the increase in diseases. There are some conventional methods of measuring the pollutants in the air as much as in the water. However, these methods are limited in the way of cost, time as well as installation sites [Choi et al., 2009]. The WSN technology has entered this domain of scientific research as well.

There are several deployments conducted in rivers, lakes, landfill sites to measure the extension of the pollution. As we all know landfills, sites for the disposal of waste materials with the method of burial, are areas with one of the major gas releases in the environment [Wiki 2012]. Of course this is not the only way of air pollution, there are the factories, cars, etc. so several deployments have been set up for monitoring pollution. Regarding to the water pollution, the major contributors are the chemical factories, which drain all the chemical waste to the nearest rivers and lakes. There are methods of measuring water contamination as well but again not efficient for the same reasons as for air pollution measurements.

WSN exploitation has already begun from scientists for measuring the real quantities of air and water pollutants and to show us the situation we are exposed to. Except for the deployments mentioned in this thesis, there are some others that are on-going but are not included in the tables below because of lack of information.

5.1 *Air-water quality monitoring components*

The goal of monitoring the air and water (usually drinking water) quality is to make assessments of the pollution level, so that appropriate measures to be taken. With the use of WSN technology these assessments will be reliable and accurate.

The existing deployments have been installed mostly in landfill boreholes, in lakes and rivers. In some cases, these deployments have been tested in labs, using special chambers (Appendix C). The duration of these deployments varies from days to months [Collins et al., 2009 and Fay et al., 2009]. In most of the deployments, the size of the covered by the WSN area is not mentioned but from the number of nodes used one can estimate that the area size is relatively small, with the exception of [Corke et al., 2010]. The monitored subject is in some cases one particular chemical element [Shepherd et al., 2007], while in others the main pollutants [Choi et al., 2009 and Capella et al., 2010]. The topologies used in water quality assessment are tiered, multi hop comprising of static and mobile nodes, also star has been used in several cases, where the WSN is small. The fixed nodes are the ones floating at the surface, while the static are robotic boats or Autonomous Surface Vehicles (ASVs) [Corke et al., 2010]. The deployments for air pollution, on the other hand, are small in number of nodes and simple usually single hop topologies. Lastly, the measured factors in air pollution monitoring are usually methane (CO_4) and carbon dioxide (CO_2), while in water quality the usual measured parameters are dissolved oxygen, water pH, salinity, phosphate and chlorophyll concentrations.

The most known node platform being used are the Mica2s and Mica2Dots [Shepherd et al., 2007]. The usual platform is that of Fleck family (Figure 12), which is Australian and is used by most Australian deployments. GPS modules have also been used in some cases [Capella et al., 2009 and Corke et al., 2010]. The sensor nodes in water pollution monitoring are usually scattered at the surface, at about 2m distance one from another, while in air pollution monitoring the sensor nodes were set inside of boreholes (one node in one borehole). The number of nodes varies. Protective cases were used in almost all of the deployments. In addition, in two projects there have been used robotic vehicles [Corke et al., 2010 and Ong et al., 2004]. They include board platforms, GPS modules, compasses, sensors and power supply modules. The sensor used are either same with the static nodes or additional ones. The communication is done using often Wi-Fi and for power supply, batteries or solar panels are included.

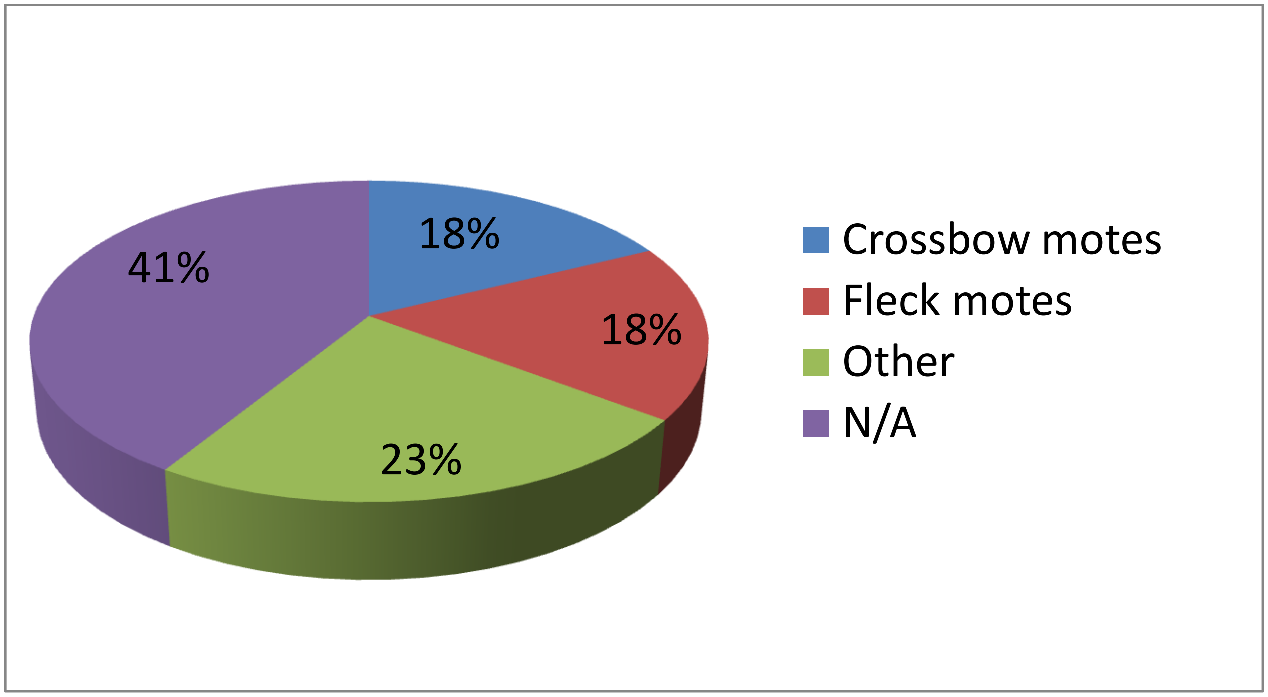

Figure 12: Node platforms

The WSN in monitoring air and water pollution is time-based, with varying sensing intervals from some minutes to couple times a day and the transmission of data is done in single hop or multi hop way. As for the operating system, in half of the deployments is not mentioned while in others, in this case, different OSs were used such as FleckOS (FOS) and because some node components, like gateway and mobile nodes being PC-based, was used Linux OS. Of course in some deployments TinyOS was used as well (Figure 13).

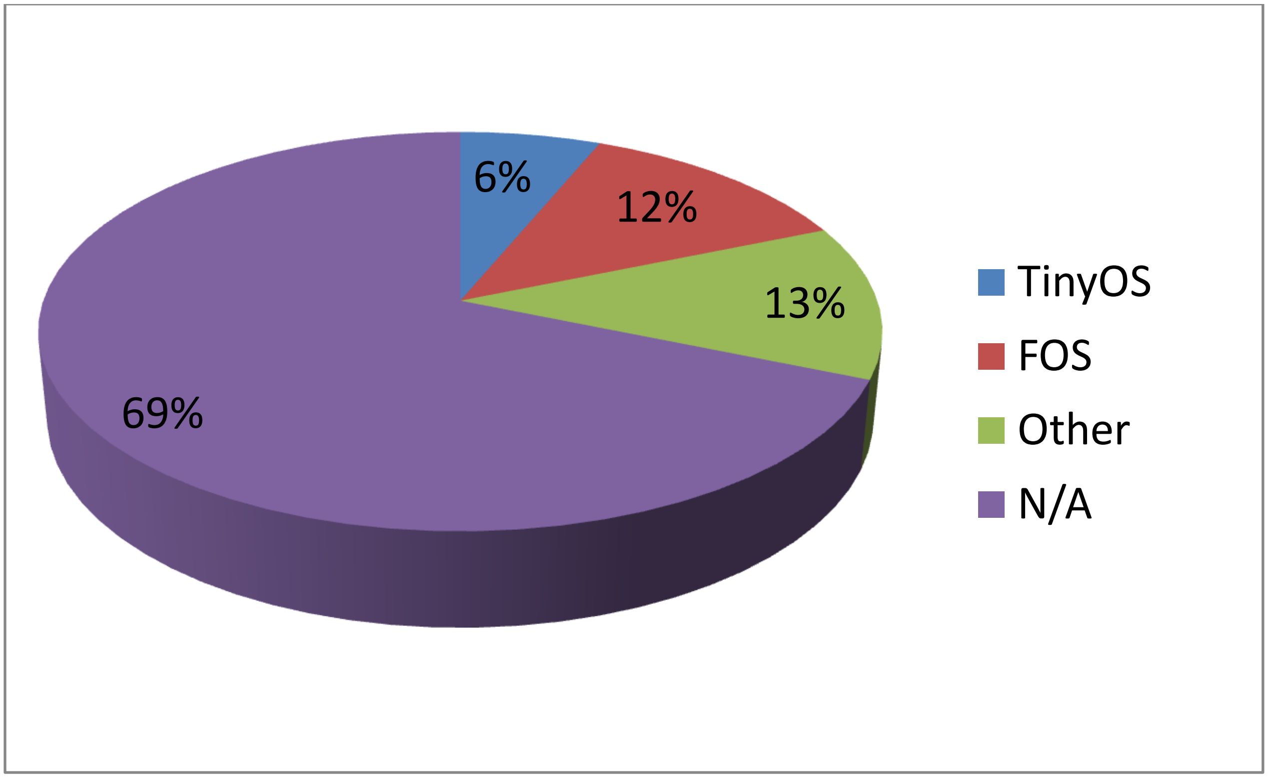

Figure 13: OSs used

Regarding the network issues, RF and Bluetooth technology was used for short range communication between fixed and static nodes with gateways and the BS. Also, cellular network was used in these deployments.

As about battery issues different types and sizes of them were used and in some cases car batteries were used also. Except for solar panels, there was use of regulators, adapters, power outlets and UPS. Sleep/wake up cycle for management techniques, electrical switches for turning off the gas sensors when no needed are some of the power management techniques.

Maintenance tasks are necessary especially for the nodes that are at water surfaces, as these come into direct contact with various substances existing in water. In one deployment, the team installed anti-biofouling mechanism, which provided automatic cleaning without the need of maintenance task by the team [Capella et al., 2009]. The cost of sensor nodes is about the same with the previous deployments, what is different here is the use of robotic vehicles, which certainly increase the total cost much more.

5.2 Air-water quality monitoring guide

Initial assessment, as has been mentioned in previous sectors is essential and unavoidable. Beginning with the monitoring subject, either air or water pollution, the deployment area include landfill gas detection or lake or river deployment.

In landfill monitoring the deployment is simple, because the sensor nodes are placed inside boreholes and then with a star topology e.g. with a sink node to gather the information, the monitoring process is done. In water quality monitoring, if the deployment is large including about 50 sensor nodes, there must be also mobile nodes for easy and smooth gathering of measured factors. The topology in this case will be tiered and multi hop. The sensed parameters depend on the monitored subject.

Regarding the hardware issue, again Crossbow Micas can be used but also the Fleck platform, which is proved to be efficient in water cases. GPS module can also be used, however one must take into consideration its power consumption, which is high so someone that cannot provide large amount of power, GPS is not recommended. The sensor nodes which are put at the water surface, have their sensors underwater, since we are talking about water pollution monitoring, so they must be placed properly and with the appropriate weight in order to be as stable as possible and not carried away from their initial placement. The waterproof case is always a must, especially if using the nodes in water, where they called buoys due to their flotation. If one could afford to use ASVs as mobile nodes, then the aforementioned components must be included.

Here the real time data is also not essential as for the data to be accurate. So the sampling time can be set to every hour or even four times a day and the transmission can be implemented with the sensing time. If there will be mobile nodes, then they will download the data at regular intervals. As for the protocols and algorithms, must be used all the appropriate ones, while the node OS can be either FOS if Fleck platforms are used or TinyOS for Micas or in case of PC-based sink/gateway nodes, Linux is efficient one.

About the communication issues, RF and Bluetooth can be used, except that the last one is more expensive, so one that cannot afford it can use RF which are very efficient for short-range communication. For nodes that are underwater, the communication is implemented through acoustic waves, due to their better propagation in the water, so the uplink sink node include both RF and acoustic modules, the underwater nodes include only the acoustic module while the BS only an RF module [Ong et al., 2004].

As for the power supply, many types of batteries can be used, rechargeable for sufficient power combined with two solar panels, depending on the deployment components used in the WSN and the duration of the deployment as well as on the number of sensor nodes and whether there are mobile nodes. Management techniques are necessary for stable, balanced and long term function of the WSN.

The cost depends is almost the same with previous mentioned ones, however it may dramatically rise with the use of the ASVs. Maintenance must be implemented for proper function of the sensor nodes, unless if there are no power limitations, there can be used internal cleaning mechanism.

Deployment duration	Area size	Measured factors	Topology/Architecture	Node platform	Microcontroller	Radio transceiver	Memory size/type	Sensors	Installation
Months for obtaining more sufficient information about the pollution either air or water	Depends on the number of nodes	For air pollution the most common are methane and carbon, while for water pollution are dissolved oxygen, water pH, salinity, phosphate and chlorophyll concentrations And many other depending on the monitored subject Note that not every node will include all the sensors	Mostly tiered – multi hop topology	Mica family and Fleck	Depends on platform	Depends on platform	Depends platform	Maybe internal of the platform or external with the use of sensor board	In water pollution the nodes are scattered at water surface not very distant from one each other and in the air pollution they are placed inside boreholes

Table 5: Air-Water pollution WSN

Sensing & sending measurements	No of nodes	Protocols/Algorithms	Node OS	Network	Power supply	Waterproof case	Maintenance tasks
Time-based every one hour or four times a daysensing and data transmission, except if using mobile nodes, which in regular intervals will gather the data	Maybe 5-10 nodes is sufficient for small deployment	Communication, routing, synchronization, energy efficiency and any other is needed	FOS or TinyOS	RF and acoustic waves for underwater nodes Wi-Fi, between GW and BS GSM/GPRS for remote connection	Li-ion rechargeable or lead acid Two solar panels and sleep wake cycle and one of the power techniques used in existing deployments	YES	Due to some sensor nodes which will be put inside water, cleaning is necessary task

Table 6: Air-Water pollution WSN (continues**)**

CHAPTER 6

WSN IN DESTRUCTION PHENOMENA MONITORING

GUIDE FOR WSN DEPLOYMENT

6. Destruction phenomena

Destruction phenomena are often in the last decades, including flooding, earthquakes, volcano eruptions, landslides, etc. Scientists conflict whether it is normal or these are the last decades of life, for some even the last year.

Monitoring these events is hardly manageable with the existing methods. WSN technology gives solutions even in these hard to monitor phenomena. In the last decade, there have been conducted several deployments with some that are ongoing. The deployment sites are volcanoes, areas with landslide events almost every year, in forests for wildfires detection and in areas with flooding danger. Some of these deployments are in their initials stages and have not been used yet under real environmental conditions however they will be in the near future.

Some deployments were conducted in labs, although most of them are real.

6.1 Destruction phenomena deployments

In case of wild land fires, mesh and tiered topologies were used, including among the usual devices, web cameras for area surveillance. The common sensors used are temperature T and relative humidity RH, wind speed and direction for fire behavior prediction and many more. The terrain characteristics are grassy, full with trees and in some cases in various elevations. Most of these deployments are field trials with prescribed fires (Appendix D).

In the part of the hardware, new platforms were used such as Linksys WRT54GL and Soekris net4801, a Mica2 is also used in one case (Figure 14) [Lloret et al., 2009 and Hartung et al., 2006]. The antennas that are mostly used are omnidirectional. The installation of nodes was done after careful area evaluation and placing of cameras and access points, so that the nodes have been placed within their coverage. Enclosure are used for node protection from fires, even though they were put near to them with high possibility of damage. The WSN is time-based, with usual sensing intervals at 10-15min. it is time-based because the firefighters must know every time the different prevailing conditions, due to the unstable nature of the fire.

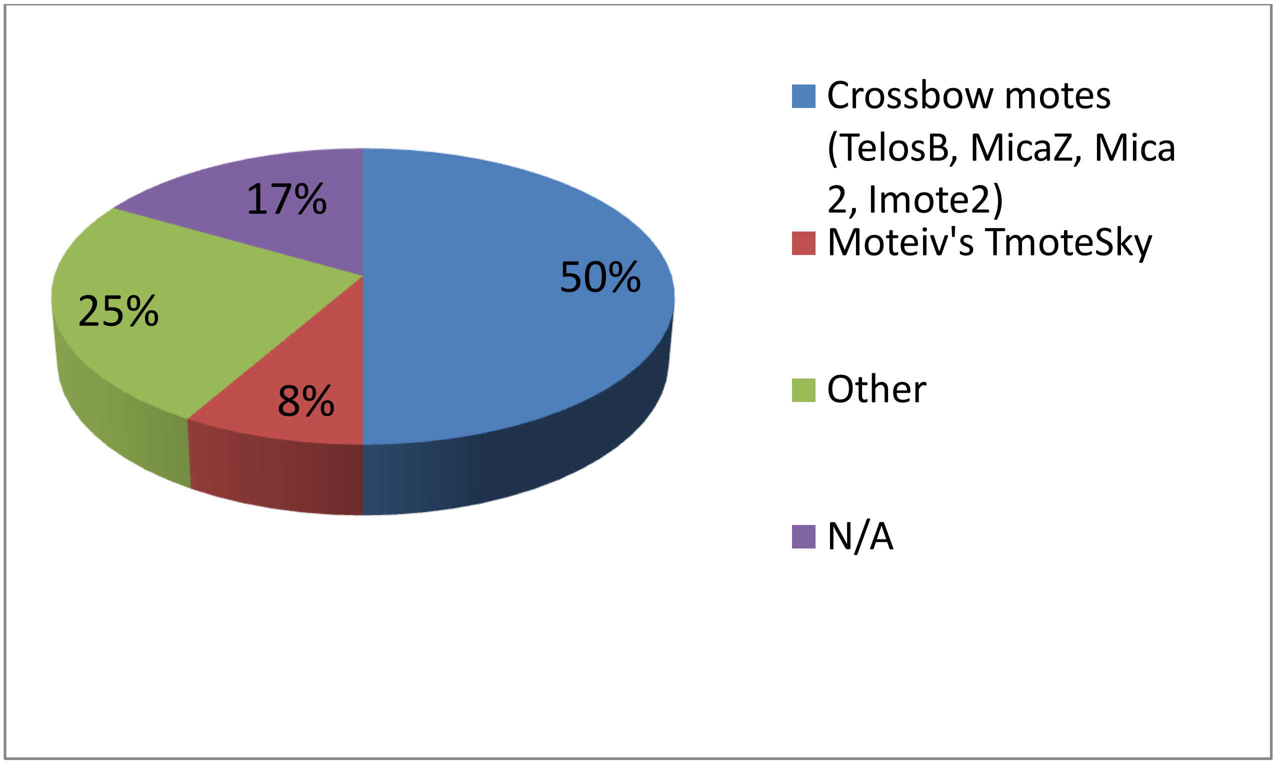

Figure 14: Node platforms

Among other protocols and algorithms, there was used the MPEG4 compression algorithm for image and video compression, due to their huge size. The sensor node OS that was used are ManstiOS, Linux and TinyOS (Figure 15).

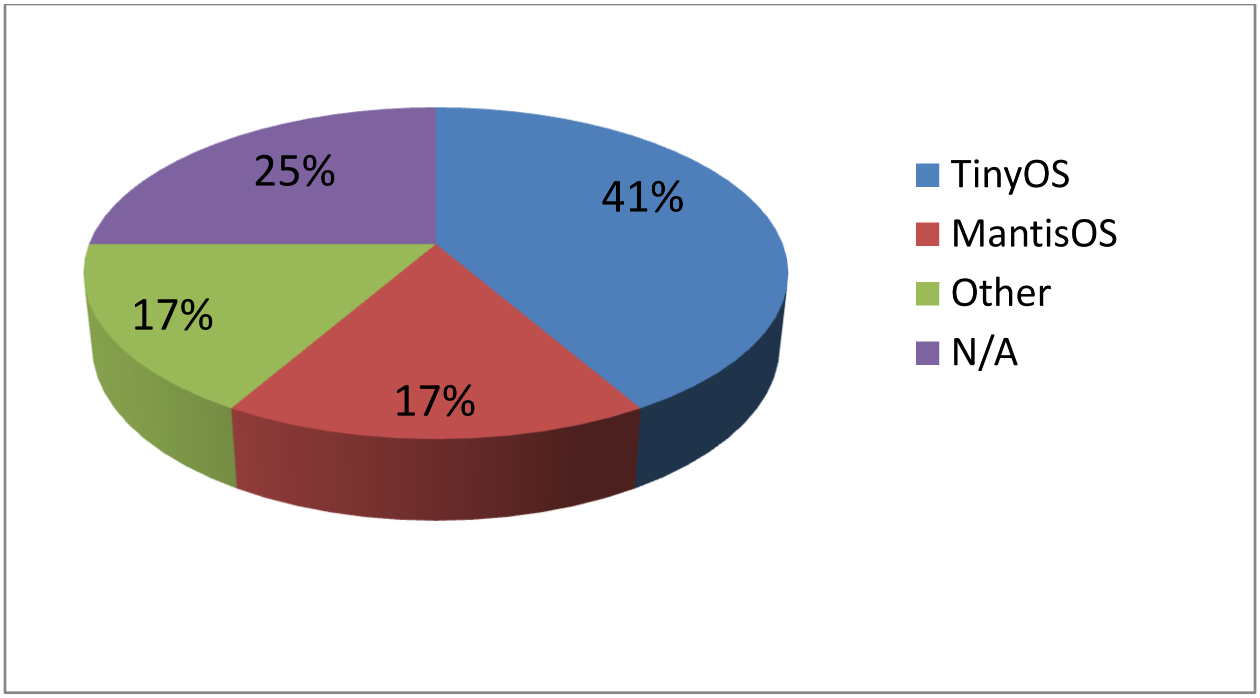

Figure 15: OSs used

As for the network, RF for the node communication as well as ZigBee and LAN802.11g, Ethernet for BS communication with backbone, which was located in a campus and optic fiber 802.11u for access points. Also a satellite dish was used for communication coverage in remote regions. For the power supply, large batteries and solar panels were used to cover the need for power.

As for the volcanoes, multi hop topology is used. The volcanoes where the deployments were set are the Mount St. Helen's near to Washington, Reventador and Tungurahua which both located in Ecuador. The sensors that are used in volcano monitoring are seismic, infrasonic, geophones and others. These sensors measure earthquakes, volcanic activity, ground deformation, etc.

Crossbow motes are the dominant platforms in volcano deployments like TmoteSky, Micaz and Mica2. The antennas used are omnidirectional and high gain Yagi. In volcanoe monitoring, the sensor nodes and the other components are fixed on tripods and called station nodes. All the necessary components for monitoring are attached in these station nodes. Regarding the installation of the station nodes, in some cases the deployment is air-dropped when there is no other way to visit the area and are placed inside the crater or around the volcano flank, with the encapsulation of the nodes [Song et al., 2009].

The WSN in this case is mostly event-driven, as it is normal. Thresholds are being predetermined and whenever this threshold is exceeded, then the will be conducted the transmission with the sampling rate being at 100Hz.

As it is expected due to platforms used, the TinyOS operation system is implemented. Many protocols and algorithms are used in order to proper and accurate function of the system. One of these are Z-SYNC hybrid time synchronization protocol that combines GPS & FSTP merits, MultihopOasis data collection routing protocol, Cascades data dissemination protocol, STA/LTA(short term average over long term average) algorithm, etc.

The communication is conducting by RF and 802.15.4 for station nodes as well as between nodes and GW and BS. Also, the use of radio modems for long distance communication is recommended.

The energy supply is covered by various types of batteries including car battery and solar panels were used for battery charging. In one case, a diesel generator was used for backup supply for the BS [Shepherd et al., 2007].

The maintenance cost is low due to network's self-organizing and self-healing nature, properties that are essential for these types of deployments. The cost for purchasing these components maybe higher because of the above characteristics.

From the three landslide deployments, one was laboratory testbed. Hierarchical and grid topology was used, where the sensor nodes are installed in columns, called sensor columns. These columns are consisted of two parts the sensors, which are located underground and the computing which is located aboveground. These columns are placed inside drilled holes. Hierarchical, multi hop topology is used in landslide monitoring.

The platforms used are the Micaz, TelosB and Stargate with sensors like dielectric moisture sensors, geophones, strain gauges sensors, pore pressure sensors, etc. the number of sensor columns is small, except that conducted in lab. The reason is that, there very few real deployments, as far as I'm concerned.

Here too the WSN is time-based, with average sensing time at about 10min in multi and single hop communication. Among other protocols and algorithms, landslide prediction algorithms were used. Of the few deployments, only in one is mentioned the node OS which is the MantisOS. RF and Wi-Fi communication was mostly used for motes as well as GPRS for remote communication.

Rechargeable batteries were used for power supply and solar panels for battery charging. Algorithms and duty cycling were used for power management, also regulators and negative voltage converter as well. As for the cost and maintenance issues, there is no available information.

6.2 Destruction phenomena monitoring guide

To begin with, someone who is interested in deploying a WSN for monitoring a hazardous event, must select the phenomenon for monitoring, which comes with the area, e.g. if one wants to monitor and detect landslide events then the area have to be near a mountain. So depending on the deployment area, there will be different landscape and terrain features, something that affects the WSN design system.

Hierarchical, multi hop topology is proposed, based on the existing projects. The sensors again depend on the monitoring subject and may be the aforementioned. Of course the chosen ones must as accurate as possible. The platform choice can be one of Mica family, which we found to use in many deployments, proving their reliability and robustness. Also the installation is based on the under monitoring phenomena. Use of protective boxes is critical issue and must be implemented because of the hazardous conditions.

Sensor sensing is time-based in landslide and wild fire monitoring, while in volcanoes is event-driven based on predetermined threshold. The use of proper protocols and algorithms must be considered because the WSN must be robust, self healing and self maintaining due to the fact that the frequent visits in the deployment area will difficult. The OS choice will be based on the platform choice, however the use of TinyOS, which is compatible with many existing platforms is a good choice.

RF and Wi-Fi are the most common ways of communication, of course the available infrastructure must be considered. As for the power supply, there are many solutions of what batteries to use, depending on deployment duration and the components used in the system. Solar panels are indicated for use if there are appropriate weather conditions and of course power management techniques must be an integral part of the WSN.

Deployment duration	**Deployment area size**	**Topology/Architecture**	**Node platform**	**Microcontroller**	**Radio transceiver**	**Memory size/type**	**Sensors**	**Installation**
The system can be set prior to the period of landslides occurrence	Depends on the number sensor columns, but generally the highest, the better results will be obtained.	Mostly tiered – multi hop topology	Mica family	Depends on platform	Depends on platform	Depends platform	Maybe internal of the platform or external with the use of sensor board -Pore pressure sensors -Dielectric moisture sensors -Geophone - Strain gages	The sensor columns are placed vertically in drilled holes near or in the area of intresting

Table 7: Landslide detection

Sensing & sending measurements	No of nodes	Protocols/Algorithms	Node OS	Network	Power supply	Waterproof case	Maintenance tasks
Time-based every 10-15min	In my opinion 8-10 is enough for the beginning	Communication, routing, synchronization, energy efficiency and any other is needed	MantisOS or Tiny OS both are compliant with Mica family	RF between nodes Wi-Fi, between GW and BS GPRS, if available for remote connection	Rechargeable lead acid Solar panels and sleep wake cycle as well as special algorithms for energy conserving	YES	If the deployment is long term

Table 8: Landslide detection (continues**)**

Deployment duration	Deployment area size	Topology/Architecture	Node platform	Microcontroller	Radio transceiver	Memory size/type	Sensors	Installation
The system can be set prior to the period of high danger of fires	Depends on the number of sensor nodes	Mostly tiered – multi hop topology	Mica family	Depends on platform	Depends on platform	Depends platform	Maybe internal of the platform or external with the use of sensor board T -RH -Wind direction & speed Among others	The sensor nodes have to be placed strategically, in a way to be covered by web cams and near the fires.

Table 9: Wild fire detection

Sensing & sending measurements	No of nodes	Protocols/Algorithms	Node OS	Network	Power supply	Waterproof case	Maintenance tasks
Time-based every 10-15min	In my opinion 8-10 is enough for the beginning	Communication, routing, synchronization, energy efficiency and any other is needed	MantisOS or Tiny OS both are compliant with Mica family	RF between nodes Wi-Fi, between GW and BS GPRS, if available for remote connection	Rechargeable lead acid Solar panels and sleep wake cycle as well as special algorithms for energy conserving	YES	If the deployment is long term

Table 10: Wild fire detection (continues)

Deployment duration	Deployment area size	Topology/Architecture	Node platform	Microcontroller	Radio transceiver	Memory size/type	Sensors	Installation
The system can be set all year around	Depends on the crater size, which has usually large diameter	Tree-based multi hop topology	Mica family	Depends on platform	Depends on platform	Depends platform	Maybe internal of the platform or external with the use of sensor board -Seismic sensors -Infrasonic sensors Accelerometer and geophone sensors and others	The sensor nodes have to be placed strategically, either inside the crater or around the flanks of the volcano and for their installation possibly a helicopter may need to drop the sensor stations (an extra cost)

Table 11: Volcano monitoring WSN)

Sensing & sending measurements	No of nodes	Protocols/Algorithms	Node OS	Network	Power supply	Waterproof case	Maintenance tasks
Event-driven	Around 10 sensor stations, based on existing deployments and of course based on the budget	Communication, routing, synchronization, energy efficiency and any other are needed	Tiny OS	RF and 802.15.4 between nodes No cellular infrastructure is available near volcanoes Long distance radio modems for remote communication to BS	Various types can be used Solar panels for recharging The event-driven mode is energy saving	YES	If the deployment is long term, however it is difficult task

Table 12: Volcano monitoring WSN (continues**)**

CHAPTER 7

WSN APPLICATIONS IN LIVESTOCK AND WILDLIFE MONITORING

GUIDE FOR WSN DEPLOYMENT

7. Livestock and wild animal monitoring

The animal kingdom has always attracted human curiosity in observing and learning about them, due to the natural need of learning about his origin. In the past, animals monitoring was conducting with human presence in their habitat areas, something that was dangerous for human integrity as well as invasive towards animals or with their captivity in labs. In the last decades, monitoring task was implemented using people with cameras or placing camouflaged cameras, which was not effective in all cases. Even more recently, the use of wireless sensor nodes deployed in research area, a relatively new technology, according to initial deployments have been proved effective as much as necessary from now on.

As it has become obvious from the previous sections, WSN technology is being already applied in many scientific fields. Livestock and wildlife animals monitoring is one of these. WSN technology offer long term and unattended monitoring in this field, as in the others, using efficient and proper H/W and S/W.

Regarding to livestock animals, during the last years we have all been witnesses in major disease outbreaks [Kwong et al., 2011, Kwong et al., 2009]. Without close monitoring of health and other issues, many problems will arise every time [Kwong et al., 2009]. Farming industry is one of the crucial sectors, playing significant role in the economies of the world. The use of WSN comes to give solid solutions to aforementioned issues. Deploying sensor nodes in farm environments and in form of collars worn by the animals, farmers now can have full image of their livestock, giving them the opportunity for proper care.

As for wildlife monitoring, WSN provides the scientists the chance of close and long term deployment. Many species are shy in front of human presence, apart from the fact that in any cases it may prove to be dangerous, thus monitoring using traditional ways is inadequate and most reckless with the existing technology.

To date there have been conducted some real deployments in wildlife monitoring as much as in farms, which are mentioned below. Due to the fact that WSN is relatively new technology and somewhat expensive for most people, deployments number is not very important to make proper assumptions about WSNs, on the other hand it is significant for initial reports.

7.1 Animal monitoring deployments

To begin with, the existing deployments monitored frog species and birds to cows and carnivores. Although some of them, while designed for wild animals monitoring are tested with domestic ones [Zviedris et al., 2010]. There is one case of lab testing as well [Hu et al., 2009].

The monitored area mostly is large in case of an outdoor real deployment, as animals usually travel except farm animals. Of course in cases of habitat monitoring the above mentioned does not apply. The usual measured factors, except for environmental ones like temperature, humidity, light, etc., are presence of species, vocalizations and location (Appendix E). These parameters are measured using GPS as primary sensor for location, detection and identification nodes and microphones for vocalization detection [Hu et al., 2009 and Shukla et al., 2004]. The topology preferred for large habitat monitoring, is tree-based with clusters like in [Hakala et al., 2008, Polastre 2003, Szewczyk et al., 2004 and Jiang et al., 2010] while for wild animals preferred star topology.

Referring to the WSN H/W, the Crossbow's platforms are being used as well, like Mica2, Imote, TmoteSky, etc. and Flecks (Figure 16), which are dominant. One can observe, however, that in couple cases other platforms, unknown till this chapter, have also been preferred from the writers either made by them from the scratch like Carnivore platform [Rutishauser et al., 2011], or just from other company like CiNet [Hakala et al., 2008]. As mentioned in previous chapters, the MCU, radio transceiver and memory are embedded to the platforms, thus are dependent on the choice of it. The GPS is used in many deployments, as it is mentioned that animals location is one of the most measured factors. The sensors are being chosen very carefully for take as much accurate measurements as possible, like in other deployments. In all cases there are mobile nodes, except for stationary ones, which are collars worn by the monitored animal. Collar design issues such as size and weight and its installation on the animals, follow specific requirements that are and should be implemented, meaning that the size and the weight must be proportional to the physiology and weight of the animal [Wark et al., 2007]. In some deployments, stimuli including vibrations, noise and light electroshock was implemented, which also must follow the proper requirements, according to animal ethics and welfare [Wark et al., 2007]. Last but not least, protection of the node components is a must here as well.

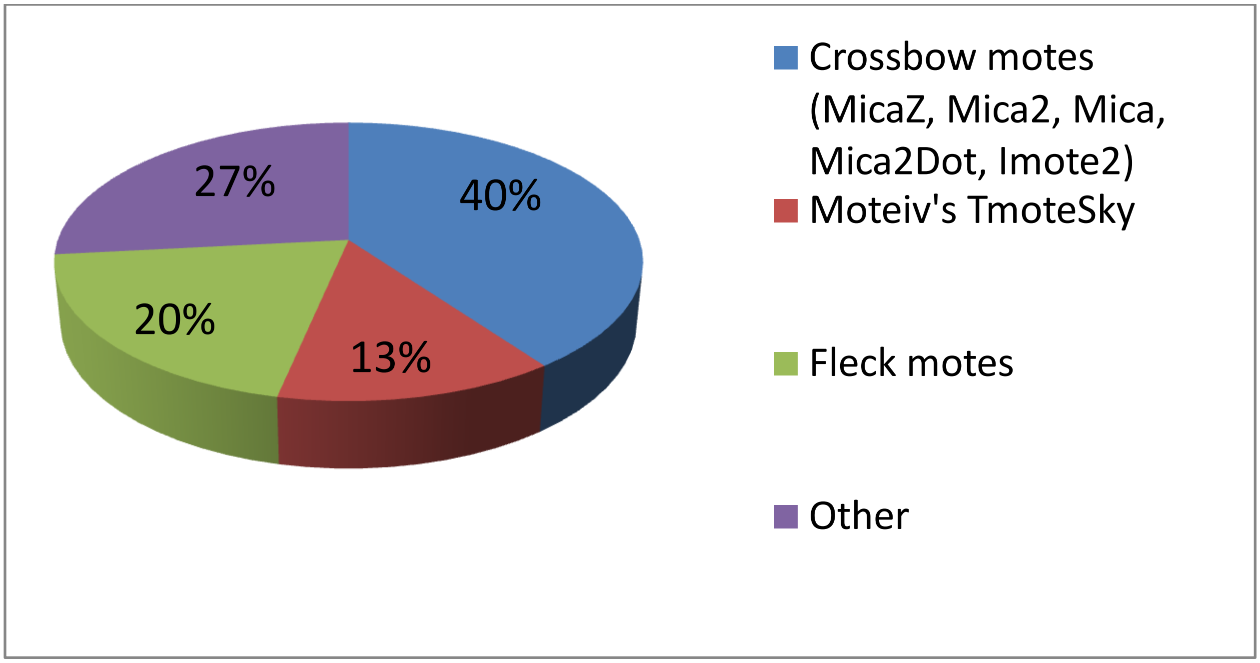

Figure 16: Node platforms

The WSN in monitoring animals is time based, according to the deployments, with the sensing time varying from every second to every hour. The sampling rate is mentioned sometimes as well. Many protocols and algorithms are used for proper function of the nodes and effective power management. The TinyOS operating system is one more time mostly used (Figure 17), however there are some others implemented such as ContikiOS [Dyo et al., 2010] an event-driven OS, MansOS [Zviedris et al., 2010] and ImpalaOS [Zhang et al., 2004].

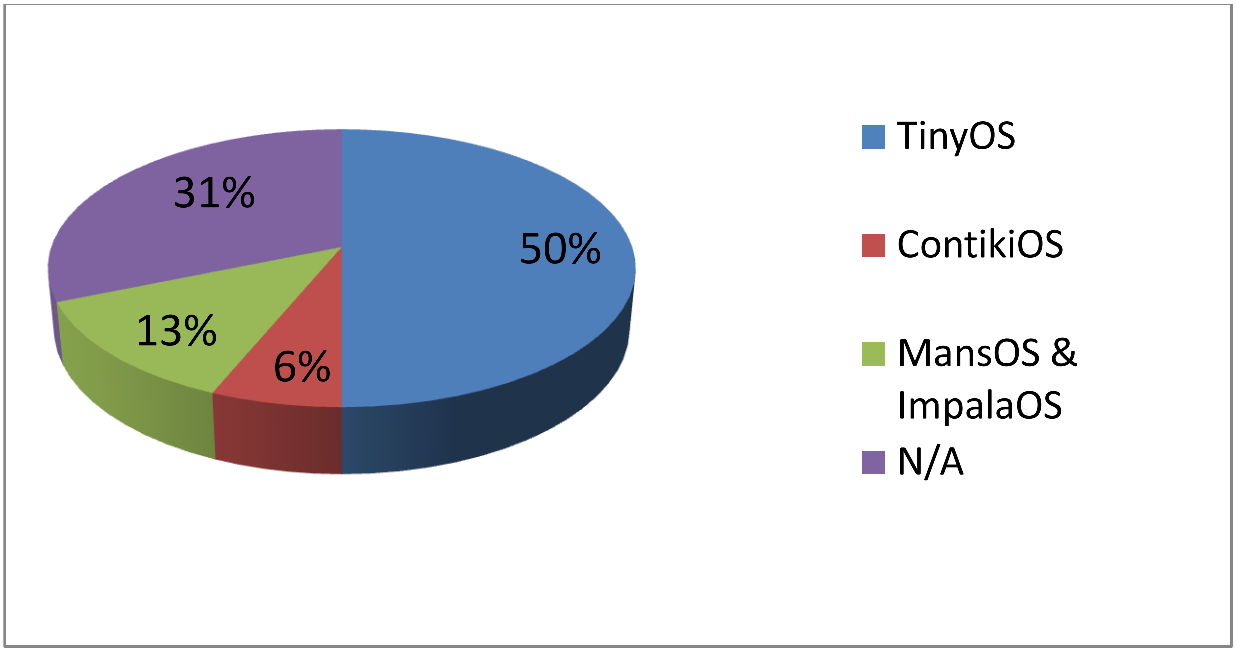

Figure 17: OSs used

The communication issue is implemented using, mostly, RF and Wi-Fi for nodes/collars. Cellular is not preferred in these cases, except for one case [Dyo et al., 2010], due to absence of coverage usually. Satellite connections are also used for direct access to WSN for remote users. As for the power supply, various types and sizes of batteries were used mostly rechargeable, with solar power as charging unit. In one deployment electricity was used for power supply of the system, as it was available to use [Hakala et al., 2008].

The cost of purchasing sensor nodes for animals monitoring is not mentioned in most of the articles. However, from some that was mentioned it is expensive enough because of the components used for animals monitoring [Kwong et al., 2009, Rutishauser et al., 2011 and Shukla et al., 2004]. Maintenance tasks are also not mentioned. There is another factor that must be considered in these kinds of deployments and is referred to damage possibility. Due to the fact that, the sensor nodes/collars are installed on animals or in their habitats, it is very likely for them to cause damages to these equipments, so is evaluated as Low, Medium and High possibility, depending on the animal species and size.

7.2 Cattle monitoring guide

One who wants to deploy a WSN system in a farm to monitor his livestock, first of all have to consider the deployment period and the budget. Generally, one of the attracted characteristics of WSNs is the fact that it is easy to deploy for someone who is not familiar with these kind of technology. After the budget consideration, HW decision must be made. Based on the existing deployments, Fleck^{tm} 1 & 2 platforms with the embedded components are a good choice, as they were used mostly and effectively as well as due to its design especially for animal tracking and control [Guo et al., 2006]. The number of collars depends, firstly, on the number of animals for monitoring and on the radio coverage, which in this case can accommodate large number of collars, however the cost in money as much as in power consumption will be higher. The installation part in this case is easy enough, as the animals are cattle. The monitored parameters are depend on the nature of monitoring, that is for cattle health like temperature, behavior like location or environmental effect like humidity, light intensity, etc. or combination of these. Someone who wants to control the behavior of animals like bulls must include actuator nodes, which will apply some kind of light stimuli to prevent e.g. bulls from fighting in mating season, where they are extremely aggressive [Wark et al., 2007]. As for the topology choice, for habitat monitoring tree based must be preferred. On the other hand monitoring animals like cows, carnivores or European budgers (Meles meles) with collars, the animals will be spread out in the woods, thus the transmission of the data have to be implemented when 2 or more collared animals will be in range of communication between them or with BS or, forming star topology [Rutishauser et al., 2011].

The sensing of the parameters will be time-based, as we want to know the temporal changing of the measured factors throughout the deployment. For smaller WSNs the communication can be single hop while for large ones it has to be multi hop, because the distance from some nodes to deliver successfully their data to the sink node will long, so they must send the data through other nodes.

Regarding to SW issues, all the appropriate protocols and algorithms must be implemented for proper function of the WSN system, as it was mentioned in previous sectors. The operating system run in Fleck^{tm} platform can be TinyOS, of which the performance is reliable according to the existing deployments and in other fields as well. As for communication between the nodes and with a BS RF or 802.15.4 is the most suited.

For power supply, batteries will be used like NiMH ones with the combination of duty cycle or sleep wake mode. If the deployment is for long period, then the use of natural sources for battery charging must be used, with the most common, solar panels, if the climate is favorable of course. Lastly, risk assessment have to be considered, for there will be in some cases node damages as in [Wark et al., 2007].

Deployment duration	Deploymen t area size	Topology/Architectu re	Node platform	Microcontroller	Radio transceiver	Memory size/type	Sensors	Installation
Depends on budget mostly	Depends on farm size For wild animal monitoring the area is usually large, in sq m	Tree-based clustered topology for habitat monitoring Star for collared animals monitoring	Fleck^{tm} Crossbow motes	Depends on platform	Depends on platform	Depends platform	Depend on the monitored parameters	The collars will be worn on the animals neck

Table 13: Cattle-Wild life monitoring WSN

Sensing & sending measurements	No of nodes	Protocols/Algorithms	Node OS	Network	Power supply	Waterproof case	Maintenance tasks
Time-based Sensing time depend on power supply and the application that is, using actuators the sensing must be frequent	Depend on budget and the animals monitored	Communication, routing, synchronization, energy efficiency and any other are needed	Tiny OS	RF between nodes and BS And in wild animals case satellite connection for remote communication	Various types of batteries can be used Natural sources for recharging like photovoltaic system	YES	For changing the batteries maybe and replacement of possible damaged collars

Table 14: Cattle-Wild life monitoring WSN (continues)

7.2.1 Wildlife monitoring guide

For wild animals monitoring some issues are the same with the above ones, such as budget assessment.
Regarding to the platform choice, one of the Crossbow motes may be used like Imote, Mica2, TmoteSky, etc. depending on the requirements of the particular deployment. The environmental parameters measured, as part of the animal monitoring process, are the known. Other factors that can be measured among others are presence of the animal, vocalization and location. The appropriate topology is referred above.

One who wants to detect and identify animal species, must include detector nodes with PIR sensors and camera nodes for identification [Garcia-Sanchez et al., 2010]. Thus, additional equipment, which are the cameras must be purchased. On the other hand, for simple monitoring stationary nodes and mobile nodes/collars must be used. The sensing of the parameters is again time-based while the sampling rate (Hz) varies. The TinyOS is the most used operating system (OS).

As for the communication of the WSN components, RF like 802.15.4 standard can be applied, for remote communication and user direct connection with WSN satellite connection can be used. Power supply issue is the same with the cattle monitoring mentioned above.

The cost and maintenance issues are not available. The risk evaluation is the same with the aforementioned (tables 11&12).

CHAPTER 8

OBSERVATIONS - OTHER WSN APPLICATIONS

8. Additional observations

Prior to a WSN deployment, tests need to be conducted either through simulations or through testbeds in labs or even outdoors. Most of the outdoor tesbeds in mentioned deployments were implemented in campus areas. The purpose of these preliminary tests is to address as much issues as possible, because unfortunately problems are facts, so that when the real deployment will be conducted the WSN system will have more possibilities to function almost unattended. However, some external events may affect the WSN functionality as in [Kerkez et al.] a fact that must be considered although no one can predict it. The design of a WSN needs to be consistent with the environment where it will be set up, that is except for technological knowledge of the system, one must have the knowledge of the ecosystem [Oliveira et al., 2011].

Except for sensing parameters that a WSN is designed to gather, the health of the system need also be monitored by periodical sending of status messages, which include battery level, topology, PDR, RSSI and LQI values. These metrics are used for WSN performance evaluation. The packet delivery ratio (PDR) shows the overall communication efficiency of a link between two nodes and is defined as the successfully transmitted packets divided by the total number of the transmitted packets [Kerkez et al.]. On the other hand, the Received Signal Strength Indicator represents the power of a signal arrived at the receiving antenna [Kerkez et al.]. The Link Quality Indicator is used for routing path selection [Mainwaring et al., 2002].

For WSN results evaluation in cases like air-water pollution monitoring, manual measurements need to be taken for comparison to prove the high fidelity of the data obtained by the WSN, which in most cases is proved.

In addition, the databases where the measured parameters are stored are usually an SQL DB, through which users using SQL queries are able to obtain specific information. GUI tools are used for data visualization and the existence of a web interface from where users may access any time and from any devices to monitor or the WSN is essential.

8.1 Current WSN applications worldwide

There are some deployments that have not been published in articles, though are mentioned in internet sites. These are not included in the tables due to the luck of much essential information, so in this section some of these are mentioned if anyone is interested in visiting these sites. The characteristic of these deployments is that they are designed and deployed for continuous operation.

In Greece, monitoring air and water pollution is conducted using telemetry systems such as monitoring of ground water of Strymon river basin, where the installation of 6 telemetric stations have been implemented measuring 15 physical and chemical parameters in real time. Also the system includes photovoltaic modules power supply of the system as well as remote center where the data are transmitted and stored for further analysis [11]. Another similar system for monitoring the quality of river water is the one developed and implemented in the river of Eurotas, located in Laconia prefecture, outside the city of Sparta. The sensor network have been installed in totally seven locations comprising of seven sensor stations measuring pH, water conductivity, dissolved oxygen, turbidity, water level and rain level in each station. The data transmission is implemented using the mobile network and the measurements are conducted in real time, every 10min, while the project includes a warning system as well [12]. In addition to these projects, there is the National Network of Monitoring the Air Pollutants (**ΕΔΠΑΡ**), which in 2004 included 36 monitoring stations in the whole country. These stations are equipped with data loggers, broadcasting system using modem and phone line and calibration system [13]. In addition, the wetland monitoring in Gulf of Amvrakikos is being done with the use of 4 floating sensor nodes (buoys) at the Gulf, 4 fixed nodes at rivers, 1 mobile sensor nodes and a central control system where the measured data are transmitted. This is a pilot project and the personnel who is in charge of its management, is being trained. Furthermore, for weather measurements there have been deployed meteorological sensors in Central Greece which includes temperature and relative humidity sensors, road status sensor, wind speed and direction, precipitation sensor and atmospheric pressure. Along with these, there is an IP camera as well. There is also the seismologic network which is comprised of seismological stations, deployed throughout the country of Greece [14].

In Australia there have been deployed sensor node buoys for tsunami detection in April 2007, which are DART™ buoys. They are deployed in the Tasman Sea, containing two independent communications systems as back-up. The data are transmitted via satellite connection to the tsunami warning center [15]. Another tsunami early warning system is the one deployed in the Indian Ocean, called GITEWS and is an integral part of the multi hazard warning system, which includes natural catastrophes such as earthquakes and volcanic eruptions. The sensor network is consisted of seismic stations, GPS and oceanographic equipment, the early warning system and the mitigation system, which is already under full operation [16].

Conclusions and future work

As it became obvious from the deployments already being conducted or are on-going, WSN technologies have overwhelmed almost all scientific fields. Using wireless sensor networks in outdoor environmental monitoring has proven to be an effective way of obtaining valuable information, with the use of which scientists can develop monitored phenomena models and prediction ones. These models, after their study and evaluation, will contribute for taking precautionary measurements in vineyards and in pest detection monitoring in various crops to possible prediction of the next hazardous event.

In almost every aforementioned case the WSN system performance was generally the expected one. The deployment team of every project managed to cope with undesired problems that resulted during these deployments. Of course these problems were not without a cost that is losing information from the particular sites with problems. Sometimes it would take couple of days to repair bugs, either due to difficulty to reach the monitored are because of environmental conditions or due to difficulties of finding the bugs.

The general image that was obtained from the existing deployments referring to H/W and S/W as much as networking and power supply issues is based on these projects which were implemented the last decade however their number is very significant giving the opportunity to learn from these. The guidelines that derived from these deployments are basic and based on other peoples experience, however someone who is not dealing with this kind of technologies, reading these guidelines can learn some important issues that must pay attention before completion and during a deployment set up.

Regarding to the nature of this thesis which is mostly a guide as it is mentioned before it is a generic guide and can be useful for quick start. In the future this guide could be enriched with more specific instructions for the user. In fact, there can be set WSN deployment for every of the aforementioned scientific field and develop a guide using all the existing technology for creating the most effective guide.

In spite of the WSN achievements, there are some challenges that must be addressed in the near future. These challenges are concerning the issue of power supply where alternative power sources need to be applied such as kinetic energy, wind power, etc. for long term deployments and more effective power saving/management techniques and algorithms. The price is a crucial factor in using WSN technology [Oliveira et al., 2011]. As it is mentioned earlier, the goal of this technology is to be used by everyone without special knowledge or training. However, the price is still needs to get cheaper for being able to deploy a proper WSN, which to give the right measurements have to be large in sensor node numbers. In addition, some sensor nodes like the ones used in underwater sensor networks are more expensive than the ones using in land. There are also some other important issues that need to be tackled regarding the scalability, the robustness, the remote management, etc. [Oliveira et al., 2011].

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Appendix A – Agricultural deployments

General information about deployment Agriculture							
Deployment ID	**Place of Deployment**	**Total project's/experiment's duration/chronology**	**Deployment area size/type**	**Purposes & goals**	**Measured factors**	**Topology/Architecture**	**Additional applications/observations**
39	Glasshouse with strawberries	N/A	N/A		-Plants leaf T(PT) -Chlorophyll Fluorescence(CF) -Ambient T(AT) -Ambient Light(AL) -Soil moisture(SM)	Fixed topology System architecture: -Lower level consisting of various sensors/actuators -Drivers level -Hosting node Middleware that supports the interaction with other nodes, the back-end monitoring, etc. – Application level components include the logic that specifies the conditions under which actions are to be triggered	Each sensor upon receiving the measurements, store them in its local memory, but overwrite them only after receiving an ACK
40	A selected piece of land of a University garden	During two crop seasons, i.e. 1 year	100ft^2 that is ~9.29m^2 grassy land	The system was developed for irrigation control	-T -Ambient light -Humidity -Soil moisture	Consisting of: -sensor nodes -actuator nodes -sink node -BS PC -Desktop PCs Multi hop topology	Desktop PCs were used for grid computing development SQL DB data storing All the interfaces , GUIs and decision support system were programmed in C .net language
41	Vineyards in three different area of Tuscany, Italy (NAV system)	N/A	1st vineyard in Brolio, 1ha size, at 4220m	Remote real-time monitoring &	Master unit : -Air T -Wind speed &	Multi hop topology System hardware architecture: -Sensor nodes as slave	Prior the vineyard deployments, some functional tests were conducted for the system

			a.s.l (above sea level) 2nd in Bolgheri close to the sea coast at 8m a.s.l. 3rd and 4th in Ampio at 12m and 15m a.s.l. respectively	collecting of micrometeorol ogical parameters in a vineyard	direction -Precipitation -Atmospheric pressure -Air humidity -Global solar radiation Slave unit: -Air T -Grape T -Leaf T & wetness -Soil T & water potential -Wind speed	units(SU) -BS as master unit(MU) -Remote central server	performance evaluation in the laboratory Two types of grape cultivars were used which are Sangiovese and Cabernet Sauvignon
42	Greenhouses with melon & cabbage in Dongbu Handong Seed Research Center, Korea	One month in cold winter	N/A	-	-Ambient light -T & RH	Multi hop ad hoc -A-nodes including sensors -C-node as aggregator -Sink nodes -Gateway -AP -Management sub-system consisting of a DB server, an application & web server	The communication range of A-nodes was up to 70m, but due to interfering sources inside the greenhouses, the range was reduced to 30m Based on deployment results, there was some data losses because of power exhaustions of some sensors the sensors did not show same output levels, in spite of being very accurate, due to interferences from other components in the same PCB enclosure
43	Rural area consisting of 1000 dwarf cherry trees	N/A	-	-	-Soil moisture	Architecture: -Base station unit(BSU) -Valve unit(VU) -Sensor unit(SU)	The length of the data package is 60bytes Two LEDs were added in this system for notifications
44	Fruit farm in the lower Yakima Valley near Prosser, Washington	N/A	160ha complex slopes creating variations in temperatures		-Air T	Star topology Remote units and a BS	-

45	Fertile lands with broccoli crop in Valle de Ricote, southeastern Spain	10-12 weeks	~1ha consisting of 2 small crops separated from each other by several km	-	-Soil pH -T -Soil moisture -Salinity - Ambient light	Cluster topology -Monitoring nodes -Detection nodes -Identification nodes including CMOS sensor -Crop-Gateway -FarmerCoop-Gateway	The camera features a resolution of 640x480 pixels and an angle of view of 90^o, but this camera does not take pictures and operate in low voltage The PIR sensors in detection nodes have sensing range of 10m, a detection angle of 120^o and the minimum object size is of a rabbit There was also conducted power consumption simulation using the ns2-simulator
46	Horticulture farm of ecological cabbage in the *Campo de Cartagena* in Region of Murcia, SE Spain	One crop season (~10 weeks) from the first week of March 2008 till last week of May	1000ha with 250 crop fields with herbaceous & woody crops The terrain is semiarid		-Soil moisture, conductivity, salinity and T -Air T & RH -Water electrical conductivity and T	Star topology The WSN is consisting of 2 sensor networks and 1 isolated wireless sensor -Water mote -Soil mote -Environmental mote -Gateway mote -Repeater mote -BS mote(inside the offices)	The deployment was conducted in two phases, 1st in Lab, for validation of the proposed system and the 2nd is the one described As for the deployment, there were no low-battery alerts, an indication of proper operation of solar panels The repeater mote was placed on the roof of the office providing 10km coverage between motes and the repeater
47	Vineyard area	30 days	1ha with varied elevation from 396m to 412m		-T	Grid and fixed, multi hop topology	During the deployment, there were some performance issues such as radio performance which in lab it was 92%, while in the field the probability of successful packet delivery was 77%, even after resending the packets 5

							times! The sensor network is dense, however measuring only the T in a vineyard area the deployment could be less dense
48	Dorsheimer Greenhouse with tobacco plants at University of Buffalo, NY, US	20days	N/A		-Humidity -T -Light sensors	Single hop topology Consisting of: - Sensor nodes - Gateway node - BS as portable computer	According to the results, single hop network architecture is always better solution than multi hop one, because of energy efficiency, even in larger areas
49	Potato field, Netherlands (Lofar agro pilot project)	3months		The project is aiming at the protection of a potato crop against *phytophthora* The main goal of the deployment is reveal when the crop is at risk of developing the disease in order the farmer use fertilizer only when and wherever it needed In addition to this, the system will be tested under real environmental conditions to assess its performance	-T -RH - Soil moisture -The height of the groundwater table	Multi hop -Sensor nodes -Sensorless nodes for communication improvement -Field GW - Lofar GW -Lofar server	In addition to the sensor nodes, the field is equipped with a weather station, which gathers info for luminosity, air pressure, precipitation, wind strength and direction Manually localization of sensor nodes positions The code image included collection of statistics using RSSI and LQI measurements, which at the end never managed to function There was a problem with the Deluge protocol, which occupies a large portion of the EEPROM Prior the real deployment, simulations were conducted with TOSSIM The results from this deployment were far from satisfactory, due to many resulting issues involving packet loss, improper function of MintRoute protocol, various environmental factors, etc.

50	Olive grove in Petrcani near Zadar, Croatia	Begun in October 2008	N/A	For microclimate and pest monitoring in olive grows	-Air T & H -Light intensity -Air pressure -Soil moisture & T -Image sensor -Onboard T sensor as thermostat	Hierarchical network organization with a star topology Consisting of three sub-systems: -WSN includes sensor nodes end devices (EDs) and coordinator (CO) -Gateway -Central sever	The server provides a Web page for gathered data optimization Sensor nodes measure and send service data (battery voltage, RSSI values and internal T values) after waking up. The data are sent to GW whenever the it requests sensor data The server is a generic Linux machine running an Apache web server and a MySQL DB The server application is implemented in PHP on the server side and in JavaSript on the client side The result from the deployment is that the functionality of the WSN in lab doesn't ensure its functionality in real deployment
51	Farm field in the Pavagada region, southern India	Ideally during the cropping season, ~6months	N/A	The goal of this deployment is the improvement of farming strategies.	-T & RH -Ambient light -Barometric pressure -Soil moisture	Multi hop, fixed topology Consisting of two sensor networks, clusters	Before the design of the WSN system, scientists were conducted survey to categorize the different user groups activities, in the first phase. In the second phase, interviews were conducted to collect info about the needs, regarding the WSN, of the farmers, like in [38] The results from the WSN were compared to benchmark measurements from CAOS, according to which only the pressure readings were off by 4mbar. Generally the measurements appeared more noisy than expected The system data are available to access online (http://www.commonsensenet.in/ckpura/ckpura.php)

							The deployment implementation is on-going
52	An aeroponic greenhouse with lettuces in Labu, Negeri Sembilan, Malaysia	About 1 month between 27 May-25 June 2008	640m^2	To provide a highly detailed microclimate data for plants within greenhouse, using aeroponic	-T of leaf & root zones -Light intensity -Acidity (pH) -Salinity	Star topology Sensor nodes and a hub node	The distance between nodes were less than 50m The reliability of the star topology was relatively high, with the minimum data transmission rate successfully delivered was 70%
53	Campus area, WSN performance test	N/A	N/A	-	-Soil RH -T	Tiered architecture Mesh topology for actor nodes, which cluster heads Star topology for sensor nodes Lowe level comprises of sensor nodes Higher include the actuators to control electromagnetic valves, while acting as routers A gateway A remote control system	This WSAN (Wireless Sensor Actor Network) system supports also video surveillance using video node The control center uses Microsoft SQL server as DB The gateway acts as a WSAN link for the internal network and as access point for the external one and can be divided in three modules, which are gateway controlling module, internal network interface and external network interface The GW uses an ARM-Linux as OS There have been conducted radio tests in an outdoor environment, using 1 sensor node and 1 actor node

54	Vineyard of the Montepaldi farm in Chianti area, Tuscany, Italy (1st pilot site)	1 year and a half since November 2005	Sloped area 1ha	-	Soil moisture	Multi hop, flat network topology -Sensor nodes -GPRS embedded Gateway -Remote server	GUI, accessible via web for the end users This WSN was developed and deployed in three, including the one described here, pilot sites and in a greenhouse The second pilot deployment, again in Italian vineyard, included 10 nodes with 50 sensors, 500m above sea level on a stony hill area of 2.5ha. The third one was installed in Southern France vineyard
55	Farm in Queensland, Australia	N/A	N/A	-	Presence of a particular fruit fly	Star, single hop -Including Smartphones as sensor nodes -A server	In this WSN system, smartphones were used instead of motes, inside traps to detect fruit flies The mobile phones are used as clients in client-server architecture The fruit fly detection is conducted by calculating the difference between the template image and the captured one, if the difference is larger than the threshold, an SMS is sent to a target phone along with the fruit fly image According to the results, 8 to 10 fruit flies were recognized due to low quality of images and the overall recognition precision is 80%
56	Fruit farm in Taiwan	N/A	N/A	-	-Presence of a particular fruit fly -T & H -Light intensity	Architecture: -Sensor nodes -Base node -PC	This WSN system was used in combination with a fly trap which is composed of: -A container with a lure and a pathway for fly to enter -A sensor module to detect the passing signal -An

							MCU -A wireless sensor node for data transmission The experiment was based on the biological instinct of photokinesis of fly and was performed 7 times Both antennas were tested for transmission range, where for the tabular antenna the successful transmission rate was 93% till 60m, while for the dipole antenna the transmission range was larger The packet loss for the tabular antenna nodes was less than 10% within 80m and for the dipole the packet loss was less than 1% within the same distance
57	Greenhouse planted with three varieties of roses	N/A	130m^2	To define an innovative DSS system for in-situ pest detection using cameras	Pest presence	System architecture: -cameras -Wi-Fi routers -PC server	Image recording is triggered with insect motion detection
58	Martens Greenhouse Research Center's greenhouse in Narpio town, Western Finland	One day	18x80m with dense flora	-	-T -Humidity -Luminosity	Star topology	The PC is located outside of the greenhouse because of high moisture, so for signal enforcement there is an amplifier The GW node is plugged into the PC, where the data are transmitted
59	Farm with greenhouses in Korea	N/A	N/A	The aim of this deployment is to provide alert systems in detecting agricultural fires air pollution in farms	-T -Gas (CO, CO2, HCHO, etc.) -Humidity -Illumination	Tree-based Consisting of sensor nodes (WED), routers (WR) and coordinator node (WC) + a mobile node	The mobile node was a robot platform, using the same module to fixed sensor nodes and is used to gather info from areas that cannot cover the WSN. Its maximum speed is 30cm/s Based on the results, the loss rate is less than 4% There have been conducted

							simulations for system verification with the use of TOSSIM
60	Watermelon field	2 days from 13/12/2010 to 15/12/2010	6ha	-	-Soil moisture & T -Air T & Humidity	Hierarchical topology Consisting of sensor nodes and a sink node	The routing algorithm used here was developed by the author According to this algorithm a node can be in four states, which are undecided, member, cluster-head and GW
61	3Agricultural areas at a catchment, within the river basin in Southern Finland (SoilWeather)	Two year pilot project	2000m^2 covered mainly by forest (63%) and agricultural areas (17.7%)	The SoilWeather WSN aims to temporally and spatially accurate info, data services and real time applications for water monitoring and agriculture	-Water turbidity -Water level -Nitrate conc. –Water T - Soil moisture -Air T & H -Precipitation - Wind direction and speed -Level pressure in six of the turbidity sensors	Architecture: - Sensor nodes - Weather stations - Nutrient measurement stations -Turbidity measurement stations	The weather station including all the sensors, are easy to deploy on the other hand, the ease of deployment for the water turbidity and nutrient station sensors is dependent on environmental conditions To check the quality of the sensing data, calibration samples were taken every month and were compared with those of sensors Due to the amount of data gathered from all these sensors, an automatic quality control and warning system was developed, which run under UNIX system. There have been conducted four different tests including missing data test, missing observations test, variation test and range test. The SoilWeather WSN is multifunctional network that have been used in predicting potato disease, in precision agriculture, in monitoring water quality in rivers, etc. The analysis of the WSN is conducted by assessing missing and erroneous data as well as the maintenance is needed There were various problems that

							had to be faced including the weather conditions, the location of the WSN, the bio-fouling for the water turbidity sensors and battery problems Generally a small section of the total measurements were out of the range of the limit values and the performance of the system wall relatively well The water quality data gathered from the SoilWeather was available for the participants only while the weather data was publicly available
62	Vineyard area	6 months	2 acres	To show the return in investment that would have someone deploying a WSN	-T	Grid in two-tiered multi hop topology including motes and BS	Except for T data, telemetry data (battery voltage, packet loss, routing) also was reported 16 data loggers were also deployed for mote measurements validation by experienced at the task and the process of data downloading must be conducted manually and repeated several times throughout the growing season Prior to real deployment, there was lab testing, where the radio performance was checked, which was less than 99% in the field than in the lab The data packets were sending up to 5 times to avoid data loss There were few days where the network was unstable and resetting the network was necessary

63	Greenhouse with rice plants, Louisiana State University Agcenter , US	4 months		To show the effect of greenhouse conditions on growth of rice plants	-Barometric pressure -Ambient light -RH & T	Grid, multi hop topology to cover the different varieties of plants – Mesh network Architecture divided into 3 layer: -Layer1 is the mote layer -Layer 2 Server layer -Layer3 Client layer	The data upon collected from the nodes, are stored in a PostgresSQL DB The analysis of the data is implemented with the use of Matlab and Statistics tools The Mote-View software interface that is supported from the Mica2 platform, supports also security/intrusion detection based on MSP According to the results obtained by the end of the deployment, there was no data loss, due to controlled environment of the greenhouse
64	Tomato greenhouse in South Italy	Short-term	20x50m	To reveal when the crop is at risk of developing disease	-Soil and air T -RH -CO2 concentrations	Multi hop topology -Sensor nodes - Bridge node - Repeater node	-
65	Greenhouses in China	Over a year			-T -RH -Soil moisture	Star topology Comprised of three module: node, BS and data distribution module	Client/Server mode for software management from remote data center The BS was equipped with LCD screen for the real time values display The ZKOS is a priority-based, real time and multitasking OS, which means that it gives priorities to tasks A mechanism for confliction avoidance between nodes from simultaneous data transmission was adopted The remote data center is located in Beijing

WSN Hardware										
Deployment ID	**Node platform**	**Microcontroller**	**Radio transceiver**	**GPS**	**Radio antenna**	**Memory type/ size of a node**	**Sensor**	**No of nodes**	**Installation issues**	**Waterproof case**
39	Tyndall25	Atmel ATMega128L	Nordic VLSI2401	NO	N/A	Flash: 128KB	-PAMmeter for CF & AL -Thermistor for PT & AT -Probe EC-10 for SM	10 motes of which 8 are connected to various sensors supervising an array of 3 or 4 plants, 1 node is sensorless and is used as aggregator node and the other one is an actuator node for irrigation control	The area was divided in four zones and 96 plants were placed to these zones. They were arranged in an array of 12 lines by 8plants each line. The sensor nodes were placed manually	IP-67

40	TelosB	N/A	N/A	NO	N/A	N/A	-TelosB sensors for T, ambient light & Humidity -Ech2o-20 soil moisture probes	15 (6 TelosB sensor nodes + 6 moisture nodes connected via external port, 1 mote was used as a sink and 2 nodes as actuator containing sprinklers)	The monitoring area was divided in two similar zones, in which 3 sensor nodes in each zone, were installed. The 2 actuator nodes were placed 1 in each zone and the sink node was outside of this area	N/A

41	N/A	16-bit of MU	Aurel mod. XTR903	NO	N/A	RAM Flash EPROM USB	Master Unit: -PT100(113 DIN) for air T -Pyranometer prototype with silicon photocell for radiation -Pressure sensor(XFAM 115KPA) for atmospheric pressure -Anemometer (Davis 7911) for wind speed & direction -Humidity sensor (Humerel HTM1505) -Rain collector II (Davis 7852) for precipitation Slave Unit: -Thermocouple type T for air, grape and leaf T -Water matric potential sensor (Campbell 229-L) for soil T & water potential -Prototype leaf wetness sensor -Prototype 3-cup anemometer	1 MU and 10 SUs	The MU was placed outside the vineyard, while the SUs were installed within and in every vineyard	YES
	N/A	16-bit of SU	N/A			64kbit non volotile				
42	N/A	8bit MCU	IEEE 802.15.4 compatible at 2.4GHz	NO	N/A	N/A	N/A	25 sensor nodes(A) 1 actuator (C-node) 3 sink nodes 3 industrial PC-based gateways(Pentium-M 1.6GHz)	Sensor nodes were placed in predetermined by agriculturists positions	YES
43	N/A	PIC18F452	N/A	NO	UGPA-434 omnidirection al antenna	N/A	-Decagon soil moisture sensor	1 BSU, 1VU and 1 SU	The sensor was placed 20cm below ground and 50cm away from the tree	-

44	N/A	N/A	SS100	NO	6dBi high gain omnidirectional antenna for BS	N/A	-Thermistor sensor	21 sensor nodes of which 2 act as relay nodes 1BS	The BS was placed in high elevation point and the 21 nodes were installed in strategic positions indicated by the growers	N/A
45	MicaZ for sensor nodes + MDA100CB	ATmega128L	CC2420 at 2.4GHz	NO	λ2 wave dipole antenna	N/A	-Soil S8000 for pH -Hydra-Probe II for conductivity, salinity, soil moisture and T -MTS-420 for ambient light -EC-10HS Decagon for soil moisture -PIR sensors for detection nodes	25 detection nodes in each of 2 crops, 1 identification node, 4 monitoring nodes and 1 Crop-Gateway	The identification nodes were placed on a corner of the crops, the detection nodes covered the perimeter of the crops, the monitoring nodes located inside of the crops, while all these nodes are under radio coverage of the Crop-GW	N/A
	Imote2 for identification + Multimedia Sensor board IMB400 & detection nodes + ITS400CA	Marvell PXA271 XScale and a Coprocessor MMX DSP	CC2420 at 2.4GHz		Integrated antenna	SRAM: 256KB SDRAM: 32MB Flash: 32MB				
	Prototype design for crop-gateway	N/A	XBee		N/A	N/A				
	Connector X8 for FarmerCoop-GW	N/A	N/A		N/A	N/A				
46	N/A	MSP430F1611 for soil, water, environmental and gateway motes	CC2420 for soil, environmental and gateway motes + XStream for gateway XStream for repeater, water and BS motes	NO	8 dBi omnidirectional antenna for water mote Main antenna(oudoors) for BS coverageand a 3dBi omnidirectional antenna	N/A	-EC250(Stevens) for water mote -Hydra Probe II(Stevens) for soil mote -SHT71(Sensirion) for environmental mote	10 soil motes, 10 environmental motes, 1 water mote, 1GW mote, 1 BS mote and 1 repeater mote	The two sensor networks are respectively 5.2 and 8.7km away from the BS and were installed in two crops The water mote was submerged in one of the ponds used for irrigation	YES for water mote

									the soil mote sensors were placed at 20cm and 40cm depth	
47	Berkeley/Crossbow motes	N/A	N/A	NO	N/A	N/A	N/A	65 sensor nodes of which 16 form a backbone	Mote installation in strategic manner	N/A
48	Tmote Sky	MSP430	CC2420	NO	N/A	RAM: 10k Flash: 48k	-Sensirion SHT11 for T & humidity -Hamamatsu S1087 PAR light sensor	3 sensor nodes, 1 GW node	Two nodes were placed near the plants, in the center of the greenhouse, one was placed about 1.5m(5ft) higher and the last one near to windows	-
49	TNOde for sensor nodes	ATmega128L 8-bit at 8MHz	Chipcon CC1000 at 868 MHz	NO	7cm (λ/4) antenna on top of nodes Five-meter high gain antenna for communication node	Flash: 128KB DRAM: 4KB EEPROM: 4Mbit	- Sensirion SHT75 for T & RH	150 sensor nodes + 30 sensoless ones (for sufficient communication)	The sensor nodes were installed at heights of 20,40 and 60cm, while the sensorless ones installed at a height of 75cm	YES
	Stargate for GW	X-Scale at 400MHz	N/A			CompactFlash card: 256MB				

50	FER Cvorak for sensor nodes Wavecom Fastrack for GW	Atmel 8-bit RISC AVR Mega 1281 for nodes ARM 32-bit	IEEE 802.15.4 ZigBee compliant RF chip	NO	N/A	N/A	-SensirionSHT75 for air T & H - Intersil ISL29013 for light -Intersema MS5540B for air pressure -Decagon EC-TM for soil moisture and T - Aptina MT9D131 for image ensor	-1 camera node for pest data -1air sensor node for microclimate data -1 soil sensor node for soil data -1 coordinator node	The camera and the air sensor nodes were installed at the olive trees while the soil sensor node was placed on a pole in the ground	YES
51	Mica2 + MTS400 sensor board	N/A	N/A	NO	Quarter wave antennas in ground plane ¼ wavelength whip antenna of Mica2 ¼ wavelength linx antenna and ½ wave length ground plane	N/A	-SensirionSHT11 for T & RH - TAOS TSL250D for ambient light -Intersema MS5534AM for barometric pressure -ECH2O probes for soil moisture	10 sensor nodes from which 2 were equipped with meteorological parameters sensors due to absence of microclimate while the rest sensor nodes were equipped with the soil moisture sensor	The sensor network is sparse so the 10 nodes were deployed in two clusters, where the nodes are more than hundred meters apart	YES
52	iDwaRF-168	Atmel AVR ATmega 168	Cypress CYWUSB693 5 DSSS at 2.4GHz	NO	N/A	N/A	-LM61 TO92 for T -SQ-200 sensor for light intensity -CSIM11 pH probe -WQ301 EC probe for electrical conductivity	3 sensor nodes and 1 hub node Node A include 2 T probes and a light sensor Node B include T and pH probes Node C include T & conductivity	The node A was placed inside the trough in place of a lettuce plant The nodes A and B were placed at the feed tank	YES
53	N/A	TI MSP430FG46 18 16-bit for sensor and actor nodes Samsung S3C2410 for GW	CC2420 at 2.4GHz for nodes and GW	NO	N/A	Flash: 116KB RAM: 8KB ROM: 1KB	Sensirion DB171-10	3 actor nodes 18 sensor nodes 1 GW PC control center	N/A	YES

54	Mica2 for sensor nodes	at 868MHz 50MHz clock MCU for GW	CC1000 for nodes	NO	N/A		N/A	13 sensor nodes + a gateway	The installation was conducted in two phases: 1st: 6 nodes were deployed 2nd: additional 7 nodes after one week The soil moisture sensor nodes were placed 10 and 35cm under the ground	YES
	N/A	50MHz clock MCU for GW	N/A			Additional SRAM: 128KB				
55	Smartphones	N/A	-	NO	-	N/A	HTC TyTNIIs with 3mp CMOS image sensors	N/A	N/A	N/A
56	TmoteSky	MSP430 at 8MHz	CC2420 at 2.4GHz	NO	Dipole and tabular antennas	N/A	-Sensirion SHT11 for T & H -Hamamatsu S1087 for light	6 sensor nods of which one was the base node	The base node was placed at the origin for data packet reception & connection to the PC The 5 sensor nodes were placed at 20, 40, 60, 100 and 120 m above the ground	N/A
57	-	-	-	NO	Wi-Fi antenna	N/A	-	5 wireless cameras	The cameras were placed uniformly horizontally	YES
58	Sensinode Micro.2420 U100	MSP430	CC2420 802.15.4 RF	NO		N/A	-Sensirion SHT75 for T & H -TAOS TSL262R for luminosity -	4 sensor nodes GW node as coordinator Laptop connected to the GW as BS	Greenhouse was divided into vertical blocks and the nodes monitored one block at a time The GW was placed at the	YES

									entrance of the greenhouse Node 1 was placed 490cm away from the glazed side wall of the greenhouse, hanging at 120cm height Node 2 had 180cm distance to the side wall at 176cm height Node 3 measured the crown layer in 310cm height and above Node 1 Finally, Node 4 was placed in the middle of the greenhouse, 930cm away from the side wall at 295cm height	
59	N/A	ATMega128L	CC2420	NO	N/A	Flash: 128KB	N/A	-50 sensor nodes -1 mobile node -8 routers -1 coordinator node	The installation was done in linear form, where the WC is located in the center while the WEDs are scattered along the linear aisle	NO
60	LPC2148F	ARM7TDMI-s at 60MHz	XBEE Pro ZigBee	NO	N/A	RAM: 32Kbyte EEPROM: 512Kbyte	N/A	5 sensor nodes including the sink node	The T & H sensors were placed on wooden rods placed in the soil The soil moisture T sensors were installed at about	NO

									5cm from each other at each 5m interval and placed few millimeters below the ground	
61	N/A	N/A	N/A	Hand-held Trimble GeoXT	N/A	N/A	**Weather station sensors:** -Pt1000 for air T -AST2 Vaisala HMP50 for H -Davis Rain Collector II for precipitation -Davis anemometer for wind speed & direction **Additional parameters:** -Decagon ECHO and FDR for soil moisture -OBS3+ for water turbidity -Keller 0.25 bar for water level **Nutrient measurement station** -S::can spectrometers for nitrate conc., for water turbidity, level and T	70 sensor nodes 55 weather stations 4 nutrient measurement stations 11 turbidity measurement stations	All these components were deployed in three areas: Hovi farm, Vihtijoki suvcatchment and Lake Hiidenvesi The sensor are mainly located on land, 11of weather stations are placed I or close to potato crops for potato disease warning In the Hovi farm were measured soil moisture, weather and water quality placed at a field parcel level. The sub-catchment includes 25 weather stations and 6 water turbidity sensors	YES
62	Mica2	N/A	916MHz radio	NO	¼ wave omnidirectional mounted on the motes	Flash EEPROM	N/A	65 sensor nodes of which the 1st tier was composed of 16 motes acting as sensing nodes and routers while the 2nd tier had only sensors	The motes were distributed in a grid like pattern, 10 to 20m apart and they took about 1 person day to deploy	PVC container

63	Mica2 + MTS420 sensor board	N/A	Multi-channel transceiver at 315, 433 or 868/916MHz	NO		Flash: 128kbytes EEPROM	N/A	5 sensor nodes inside the greenhouse and 1 located outside	The placement of the sensors were according the sensing region and the optimal coverage of all rice plants	YES
64	Sensicast RTD204	N/A	At 2.4GHz	NO	N/A	N/A	-EMS200 SHT71 and RTD205 for air T & H -4-wire PT100 platinum sensor for soil moisture	6 sensor nodes 1 bridge node 1 repeater node and 1 BS	The sensor nodes were organized in grid, in two rows including 6 nodes each with 12.5m distance between the rows The nodes inside the rows has 6.5m distance from each other The bridge node were placed 65cm above the ground for improved communication, while the repeater node was placed across the bridge	NA
65	N/A	JN5139	At 2.4GHz	NO	N/A	N/A	N/A	7 sensor nodes including GW	The nodes are placed inside the greenhouse while the BS is placed outside	N/A

Camera							
Deployment ID	**Camera type**	**Camera components**	**Microcontroller**	**Memory**	**Radio transceiver**	**Image resolution**	**Frames per second**
50	N/A	CMOS camera board + FPGA board	Actel ProAsic 3	Flash ROM: 8MB RAM: 6MB	N/A	N/A	N/A
57	AXIS 207MW	N/A	N/A	N/A	-	1280x1024 pixels	10fps

Sensor node's sensing/sending data packets				Data transmission/communication	
Deployment ID	**Time-based**	**Event-driven**	**Requirement-based**	**Single-hop**	**Multi-hop**
39	Every 5min	-	-	N/A	N/A
40	Every 5min	-	-	-	X
41	X	-	-	-	X
42	Initial sensing period every 20s for testing and then every 5min	-	-	-	X
43	X	-	-	X	-
44	Every min	-	-	X	-
45	Once every 30min for parameter sensing Every 123ms for detection node	-	-	X	-
46	Every hour	-	-	X	-
47	Every 5min	-	-	-	X
48	Every min	-	-	X	-
49	Sensing of T & RH every min Sending every 10min	-	-	X	X
50	Sensing	-	Sending	X	-
51	Every 5min	-	-	-	X
52	Every 30s	-	-	X	-
53	X	-	-	For sensor nodes	For actor nodes
54	X	-	-	-	X
55	X	-	-	X	-
56	X	X	-	-	X

57	-	X	-	X	-
58	Every 15min	-	-	X	-
59	Every few seconds	-	-	-	X
60	Every hour	-	-	-	X
61	Nutrient measurements every hour All the other sensors measure every 15min	-	-	-	X
62	Every 5min	-	-	-	X
63	Every 4 hours	-	-	-	X
64	Every min	-	-	-	X
65	X	-	-	X	-

WSN's Software			
Deployment ID	**Protocols**	**Algorithms**	**Node OS**
39	Active Message Protocol(AMP) Communication protocol	N/A	TinyOS
40	ZigBee	N/A	TinyOS
41	Transmission protocol RF sync protocol	N/A	N/A
42	Light weight CSMA Multi hop ad hoc routing protocol TCP/IP	N/A	ANTS-EOS OS
43	RF sync protocol	N/A	N/A
44	N/A	N/A	N/A
45	802.15.4 CSMA/CA B-MAC	N/A	TinyOS
46	802.15.4 ZigBee	N/A	TinyOS
47	Table-driven protocol	N/A	N/A
48	ZigBee B-MAC	N/A	TinyOS
49	T-MAC MintRoute routing protocol Deluge reprogramming protocol	Delta compression algorithm	TinyOS
50	ZigBee protocol stack (BitCloud) Message based serial protocol including framing protocol in the Data link layer Application level protocol Higher layer Internet protocols like HTTP, FTP	N/A	N/A for sensor nodes
51	B-MAC protocol Multi hop routing protocol	Tree Construction algorithm	TinyOS

52	N/A	N/A	N/A
53	TCP/IP RPLRE routing protocol	N/A	N/A
54	STAR protocol (MAC layer protocol) Link Estimation Parent Selection(LEPS) protocol (network layer protocol) Dynamic routing protocols TCP/IP	N/A	TinyOS
55	N/A	N/A	Windows Mobile OS
56	N/A	N/A	N/A
57	N/A	Detection algorithms	-
58	6LoWPAN Sensinode's Nanostack protocol	Greenhouse climate control algorithm	N/A
59	CSMA/CA	FIFO BOP (Beacon Only Period) LAA(Last Address Assignment)	TinyOS
60	N/A	Location Routing Algorithm with Cluster-Based Flooding (LORA_CBF)	PaRTikle OS

61	N/A	N/A	N/A
62	N/A	N/A	TinyOS
63	TCP/IP XMesh multi hop networking protocol	N/A	TinyOS
64	802.15.4 Transmission protocol	N/A	N/A
65	TCP/IP	N/A	ZKOS OS

Network issues				
Deployment ID	**Satellite system**	**Wireless**	**Wired**	**Cellular**
39	-	RF	-	-
40	-	RF for node-to-node and node-to-sink node and for actuators-to-sink node	Serially for sink node to BS	-
41	-	RF between nodes and nodes-BS in half duplex mode	-	GSM/GPRS between BS(MU) and remote central server
42	-	RF WLAN between GW and AP & between AP and management sub-system	RS232 link Or Ethernet between GW and AP	-
43	-	RF	-	-
44	-	RF	-	-
45	-	802.15.4 ZigBee	-	GSM/GPRS/UMTS
46	-	802.15.4 between soil motes, environmental motes & GW Long distant radio modem between the 2 gateways and the repeater mote Short distant radio modem between repeater and BS	-	-
47	-	RF	-	-
48	-	RF between sensor nodes and GW 802.11 Wi-Fi between BS and end users	USB between GW and BS Or Ethernet for BS and users	-
49	-	RF from node to node and from node to GW Wi-Fi between field GW and Lofar GW	Between Lofar GW and Lofar server	-
50	-	ZigBee from node-to-GW	-	GPRS for coordinator GW to connect to Internet
51	Ground-based satellites, one in every cluster as access points	RF for motes Wi-Fi between the access points	Ethernet link between one access point and the central sever Serial connection between the GW and the BS	-
52	-	RF	-	-
53	-	802.15.4 low power for sensor nodes 802.15.4 high power for actor nodes		

		WLAN between GW and Control center	Or Ethernet	Or 3G
54	-	RF for sensor nodes	-	GSM/GPRS between GW and remote server
55	-	-	-	3G
56	-	IEEE 802.15.4 for sensor nodes	-	-
57	-	Wi-Fi between cameras and Wi-Fi router	-	-
58	-	RF	-	-
59	-	802.15.4 between sensor nodes	Ethernet between the WC and the server	-
60	-	RF	-	-
61	-	-	-	GSM/GPRS for sensor nodes to transmit data to the DB server either in SMS form or as a data call
62	-	RF	-	-
63	-	802.11 between sensor motes	ADSL connection between sink node PC based and the users	-
64	-	802.15.4 between nodes and bridge	Ethernet LAN between the bridge and the BS	-
65	-	Wi-F- between nodes and BS	-	GPRS between the BS and the remote server

Power issues						
Deployment ID	**Battery type**	**Battery capacity**	**Replacement frequency(if needed)**	**Battery estimated lifetime**	**Other forms of power supply**	**Power saving/ management techniques**
39	X	N/A	N/A	N/A	-	N/A
40	X	N/A	N/A	N/A	-	N/A
41	12V as backup for MU	12Ah	N/A	3days	Solar panel 50W	Sleeping mode whenever battery voltage dropped below threshold
	6V for SU	4.5Ah			Solar panel 9W	
42	Li-ion rechargeable	N/A	N/A	1 month	-	Ordered-based sleep scheme
43	12V for VU	26Ah	N/A	N/A	Solar panel	N/A
44	6V rechargeable	N/A	N/A	N/A	Switching power supply connected to an outlet for the BS Solar panels of 4.8W	Sleep mode
45	3AA Lithium	3000mAh	N/A	N/A	Solar panel DC/DC voltage regulator Phototransistor	Sleep/wake up
46	3AA NiMH rechargeable for soil motes Rechargeable for water and GW motes	2700mAh N/A	-	7months N/A	Solar panel TPS 5W for BS	N/A
47	X	42Ah	Every six weeks	About 6 weeks	-	Sleep-wake up mode Duty cycling
48	2AA	N/A	After about 6 months	6 months	-	Sleep-wake up mode
49	3.6V C-cell for nodes	7.2Ah	N/A	N/A	N/A	Sleep-wake up mode Delta encoding Duty cycling of 11%
	Rechargeable for GW	N/A			Solar panel for GW	

50	2 Li-ion rechargeable for GW 3-cell NiMH reachargeable for camera node	N/A	N/A	N/A	Solar panel recharging the batteries through DC/DC converter and Li-ion charger for GW and through MPPT, supercapacitor and DC/DC converter for camera node	Sleep wake up mode
51	2 alkaline for every node	N/A	N/A	Avg about 2moths for nodes with meteorological sensors 1month for soil moisture nodes	Or solar panel	N/A
52	N/A	N/A	N/A	N/A	N/A	N/A
53	3V 2AA NiMH	4000mAh	N/A	N/A	Solar power solar power controller and solar cells for actor nodes	Sleep/awake strategy
54	X	N/A	2 times during the deployment	For about 11months based on the deployment	-	N/A
55	-	-	-	-	Solar panels	-
56	N/A	N/A	N/A	N/A	N/A	N/A
57	N/A	N/A	N/A	N/A	N/A	N/A

58	1.5V 2AA	N/A	N/A	N/A	-	Periodical sleep wake up modes
59	Lithium polymer for mobile node	N/A	N/A	N/A	N/A	Sleep wake up cycle Duty cycling
60	X	N/A	N/A	N/A	N/A	N/A
61	2 6V for sensor nodes Batteries for weather station	N/A	The weather station batteries are replaced once a year	N/A	N/A	N/A
62	6 Duracell Procell D cell	42Ah	Two times during deployment	N/A	-	Duty cycling of 3% and 20%
63	2AA for motes	N/A	Once in 4 months	N/A	-	Sleep when no sensnig
64	X	N/A	N/A	Up to one year	-	-
65	4.2V Li-ion	2Ah	N/A	N/A	Solar panels	Regulated power management system Hibernation state

WSN cost/maintenance			
Deployment's ID	**Average price per node**	**Maintenance cost (in terms of labor and money)**	**Total cost/Estimated total cost**
39	N/A	N/A	N/A
40	N/A	N/A	N/A
41	N/A	N/A	N/A
42	N/A	N/A	N/A
43	$222(with one T sensor)	N/A	About $530 including all the components of BSU, VU and SU
44	N/A	N/A	N/A
45	N/A	N/A	N/A
46	Over $450(including 1 sensor)	N/A	At least $3600

47	N/A	N/A	N/A
48	N/A	N/A	N/A
49	About $250 sensor node About $1500 gateway	N/A	N/A
50	N/A	N/A	N/A
51	N/A	N/A	N/A
52	N/A	N/A	N/A
53	N/A	N/A	N/A
54	N/A	Battery replacement twice in 1.5 years	N/A
55	N/A	N/A	N/A
56	N/A	N/A	N/A
57	N/A	N/A	N/A
58	N/A	-	N/A

59	N/A	N/A	N/A
60	N/A	N/A	N/A
61	N/A	Sensor maintaining twice a year and occasionally when additional maintenance is needed The fixation of instruments is checked and fixed, if needed and the equipment is cleaned The water turbidity sensors and nutrient measurement stations need extra care The spectrometers are cleaned automatically and also manually every month The water turbidity sensors were manually cleaned in regular basis	N/A
62	N/A	Battery replacement	N/A
63	N/A	Battery replacement	N/A
64	N/A	N/A	N/A
65	N/A	N/A	N/A

Appendix B – Natural Environment deployments

General information about deployment Natural Environment								
Deployment ID	**Place of Deployment**	**Total project duration/chronology**	**Deployment landscape features**	**Monitoring subject**	**Purposes & goals**	**Measured factors**	**Topology/Architecture**	**Additional applications/observations**
1	Urban forest, near campus of Johns Hopkins University, Baltimore MD	320 days, beginning in fall 2005	NA	-	-To build data collection system for soil ecology	- Soil moisture - Soil T - Box T - Battery voltage - Light intensity	- Grid topology with motes 2m apart from each other -Sensor nodes - Static & mobile GW -Server -Web browse	- The collected data is stored in the node's local flash memory for 22 days - On-line monitoring for motes by broadcasting status messages every 2 min. - Moisture sensor precision testing before real deployment - DB implementation in Microsoft SQL Server 2005 - Packet loss 67% or higher - A static WBS is connected to a PC and a laptop, acting as a mobile BS, is connected to a mote for periodical measurement downloading - Occasional synoptic measurements with Dynamax Thetaprobe sensors for result verification. - Multiple sensor faults during the deployment - Access to the collected data is provided through graphical & Web Services interfaces -Use of weather data from the Baltimore airport (BWI) from wunderground.com and loaded to the DB
2	Permafrost area at Jungfraujoch, Swiss Alps, Switzerland (PermaSense)	About a year starting from August 2006	Elevation: 3500m above the sea	-	-To build WSN for use in remote areas under harsh environmenta	-T at depth between 10cm and max 1m from surface -Water content	-Multi hop topology between motes -Motes - TC65 GPRS extension module as GW for exchanging	-GSM/GPRS connection of WSN to Internet -Forward Error Correction scheme(FEC) -Double Error Correction, Triple Error Detection scheme(DECTED) -DB runs on Linux server -The collected data and the WSN are

					l conditions -To gather valuable environmental info -The primary objective of		data with DB over Internet - DB sink	manageable via Web interface
3	Rock glacier on Le Genepi, Switzerland (SensorScope)	Two months August-October 2007	500x500m		To provide a low cost and reliable WSN based system for environmental monitoring and to replace existing expensive solutions To help environmental engineers to address long term monitoring questions in challenging environments.	-Air temperature - Air Humidity -Soil moisture -Surface Temp. -Incoming Solar Radiation -Wind speed & direction -Precipitation -Soil water content -Soil water suction	Mesh topology -Sensor stations -Sink node -Server	-Test deployment on the campus of EPFL in July 2006 to validate the H/W design -Design & implementation of stack inspired by the OSI model -Two different types of packets: data & control packets -Priorities are given to control packets
4	A forested headwater catchment, southern Sierra Nevada CA, USA	25 days 15th September 2009	1.5-km Site elevation range from 1950m-2010m Dense-mixed conifer forest and open meadows	Water balance	Aims to develop techniques for efficient, scalable and robust WSN deployments for monitoring hydrologic phenomena.	-Snow depth - Solar radiation -RH - Soil moisture & T - Matric potential	Mesh topology Sensor & repeater nodes Embedded data-logging board Base station Embedded PC located at the base of a 60m tower	The particular research is based in a 3-way design: - Pre-deployment phase - Deployment phase - Post-deployment phase Use of WSN metrics, PDR & RSSI for performance evaluation WSN deployment began with 10 motes and the full network was operational by September 18th Network collapse by a rainstorm affected

								nodes function
5	Glaciers at Briksdalsbreen, Norway (GlacsWeb)	About 4 months during summer 2004	NA	-	The system aims to understand glacier dynamics in response to climate change	-T -Strain(due to stress from ice) -Pressure(if immersed in water) -Orientation(in 3D) -Resistivity(to determine whether the probes were sitting in sediment till, water or ice) -Battery voltage	Single hop star topology Probes(nodes) 20m within the ice & the till Base Station on surface Reference Station, 2.5km away from glacier Sensor Network Server (SNS) based in Southampton	Once a week the BS records its location, using GPS for 10min. Use of transceiver modules with a programmable RF power amplifier that boosted the transmission power to over 100mW for signal improvement The BS runs Linux At the end of the deployment data collection was able from 7 out of 8 probes and few months later only 3 managed to function The BS experienced power failure in November, thus a small team for 2 days had to repair it and reactivate it probably due to snowfall that covered the solar panels
6	A forested catchment, SW British Columbia, Canada	10 months 2006-2007	7 ha rain dominated area		To determine whether WSN technology is suitable for use by hydrologists, i.e. to test the motes reliability in collecting and storing data under complex conditions	-Air T & H -Soil T -Rainfall intensity -Soil moisture -Groundwater level -Overland flow (measured in 16 over 41 nodes) -Internal battery power, T and H	Star topology	Raw data collected from the sensors, was converted to a usable form using a conversion program written in Interactive Data Language ITL Laptop runs in Windows XP until July 2006 and after that runs in Ubuntu Linux OS Initial testing was indoor in a lab from June 2005 to January 2006 In January 2006 a pilot field test was deployed with 10 motes in the same forested catchment with the real deployment Base on this research the existed WSN technology reliable and ease of deployment enough for hydrologists
7	A forest at Purple Mountain area, near city Nanjing, China	20 days from May 2010	Wild trees + human residence	-	The deployment is being done to evaluate the performance of WSN in forested	-T -Humidity -TSR light intensity	Hierarchical & tiered network topology: - 2 Sensor patches(lowest level)	Use of Link Quality Indicator(LQI) metric for routing paths selection Except for environmental data, data packets include info such as battery voltage, link quality and package lost rate Due to environmental interferences there is unavoidable data loss, so the received data is

					environment The collected data will provide insights into the forest climate activities and ecosystem info for environmental scientists		- 2 Gateways - Base Station - Database - Website Multi hop	approximately 87% To evaluate the sampled data from WSN, for 15 days scientists took manual measurements 4 times a day for comparison. The results from this experiment prove the high data fidelity of the WSN.
8	Laboratory	15 days	-	Environmental parameters	To show the effectiveness of a WSN To provide guidelines for implementing WSN for environmental monitoring	-T -Humidity -Light level -Soil moisture	V topology	Use of embedded and external sensors MoteWorks environment for the implementations of applications Java for communication between BS and DB Microsoft Visual Studio.Net 2003 and .aspx technology for web-based application Dundas graphs for asp .net 2003 Tossim simulator
9	Suburb environment of the city Hangzhou, China	NA	Indoor & outdoor environment	-	To show a WSN performance in an outdoor environment	-T -Humidity -Ambient light	3-tiered: - Infrastructure tier composed sensor nodes and BS - Server tier including 1 PC - User tier comprised of 2 PC's Multi hop	-

10	Floodplain area of Elm Fork of the Trinity river, Greenbelt Corridor(GBC) Park, Denton, Texas USA	From March 2008 till now	260x85m Densely populated trees & grasses	Soil moisture variation	To support hydrologic monitoring & floodplain area modeling To understand vegetation distribution along the floodplain as well as responses to flooding	-Soil moisture -Onboard T & RH	Nodes are deployed along a cross-sectional transect GBC WSN: Sensor nodes BS Gateway Server Data logger Weather sensors	The deployment begun in March 2008 with 8 motes and one year later the number expanded to 16 The network topology provides an opportunity to collect a duplicated set of soil moisture variation The packet reception rate(PRR) with a maximum one-hop distance of about 30m, that motes deployed, is 95% The Remote Field Gateway(RFG) server wakes up every 10min. to collect data for 90s
11	Sandy Gnangara groundwater mound, under Bnksia woodland, North of Perth, Western Australia		NA	Water balance & groundwater recharge	To characterize the transient spatial variability of water infiltration and consequence for the water balance & groundwater recharge To provide better process understanding for management of the groundwater resource and ecology as well as providing improved	-Soil moisture -Rainfall -WSN health	The nodes are arranged in branches from the BS, with sampling nodes as leaves - 3 sampling nodes - Base node linked to a GW - Routing & gathering nodes	The Superlite is a single board computer containing Sony Ericsson GSM module The data in the DB can be retrieved and decoded using a specially devised SOAP based web service The particular WSN is a reactive network that is based on event-driven sampling, which in this case is a rainfall event Of 434total soil moisture messages only 277were logged in the DB, i.e. 63.8%, while in laboratory trials the delivery rate was close to 100%. This occurs because of outdoor complex circumstances The waterproof cases that were used here let water penetration after a month of operation that included rain storms Two types of batteries: - NiMH - LiSO2

						parameterization for the Perth groundwater model that is used as a management tool to assess safe water abstraction levels			
12	Green Orbs:	Indoor testbed	2 months	-	Canopy closure	To replace traditional techniques of estimating canopy closure in forests, which are ineffective	-T -Humidity -Illuminance -Battery voltage -CO2 content	Multi hop topology	In the campus woodland scientists conducted 2 rounds of deployments including in total about 170 nodes Simulations conducted to evaluate the communication cost of nodes with different monitoring methods Use of LQI for wireless link quality measurement The nodes in GreenOrbs reported their networking status as well, such as one-hop neighbors link quality and routing paths
		Campus woodland of Zhejiang A&F university, China(prototype)	12 months from May 2009 to April 2010	20.000m^2 or 40.000m^2 North subtropical monsoon climate					
		Forest in Tianmu Mountain, China	8 months August 2009	200.000m^2					
13	Permafrost area at Matterhorn, Swiss Alps, Switzerland (PermaSense)		Since 2008-	Elevation: 3450m a.s.l.	-	Aim to pioneer engineering as well as scientific use of next generation sensing systems in hazardous environmenta	-T -Electric conductivity -Crack motion -Ice stress -Water pressure Internal sensors: -Ambient T -RH -Battery voltage	Tiered architecture -Sensor nodes -Wireless Sensor Network -BS consisting of a PC platform -Backend(server)	The access to the deployment site is very limited all year round The server in the data backend system is running GSN

					l conditions			
14	Microclimate surrounding of a coastal redwood tree, Sanoma, CA, US	44 days	70-meter tall redwood tree	-	To monitor the microclimatic trends that affect the particular type of tree	-T -RH -Photosynthetically active radiation(PAR) -Reflected PAR	Mesh network -Sensor motes -Gateway -BS	Calibration of measured data in two phases: roof for PAR sensors & chamber for T & RH calibration

WSN Hardware										
Deployment ID	**Node platform**	**Microcontroller**	**Radio transceiver**	**GPS**	**Radio antenna**	**Memory type/ size of a node**	**Sensor**	**No of nodes**	**Installation issues**	**Waterproof case**
1	MicaZ + MTS 101 data acquisition board	NA	Chipcon CC2420 at 2.4 GHz	NO	NA	Internal flash 512KB	-Watermark soil moisture sensors -Soil thermistors	10	Installation by scientists	YES
2	TinyNode 584	NA	NA	NO	NA	RAM	NA	10	Installation by scientists	IP68
3	TinyNode	MSP 430 16-bit at 8MHz	Semtech XE 1205 at 868 MHz	NO	NA	ROM:48KB RAM:10KB Flash:512KB	-Sensirion SHT75 for air T & H -Davis Rain Collector for precipitation -Decagon EC-5 for soil moisture -Davis solar radiation for solar radiation -Zytemp TN901 for surface Temp. -Irrometer Watermark for water content -Davis Anemometer for wind speed & direction	16 stations	Special care on placement to retrieve meaningful data	IP67
4	Devices developed by Dust Networks EME Systems OWL2pe data logger board	NA	NA	NO	High-gain 8dBi mounted 3m above ground		-Ultrasonic Judd Communications for snow depth -EC-TM Decagon for water cotent -MPS-1 Decagon for matric potential -LI-200 LI-COR for solar radiation -SHT15 Sensirion for RH & T	57	Placed at 23 strategic locations prior to WSN design	YES
5	NA	Embedded PIC	NA	YES	NA	Flash ROM: 64Kb arranged in ring buffer	NA	8 probes	Installation by scientists using Ground	Polyester egg-shape

									Penetrating Radar(GPR) to determine geophysical anomalies	capsule
6	Mica2 + MDA300 data acquisition board	NA	NA	NO	NA	Internal flash: 512KB	-Decagon Devices, Inc. ECH2O dielectric aquameter for soil moisture -Rainwise, Inc. Rainew tipping bucket for rainfall intensity -Sensor Technics pressure transducer for groundwater level -Humirel HTM 2500 transducer for air T & H -Custom Weir with binary float switch for overland flow -Thermistor for ground T	41	Placed strategically to cover the different range of topographic features of the catchment	YES
7	TmoteSky	TI MSP430	Chipcon CC2420	YES	NA	SRAM: 10KB ROM: 48KB Flash: 1MByte	NA	18	The nodes are deployed in two areas within the Purple Mountain. 16 nodes(of which 1 is GW) deployed in forested area(A) and 2 nodes in human residence(B) with the BS near to area B	NA
8	MICAz + MIB520CA BS module +	-	-	NO	NA	NA	NA	3(1 of which is BS)	By scientists	-

	MDA100CA data acquisition board + MDA300 data acquisition board									
9	Mica2 MTS400CA sensor board	NA	NA	NO	NA	NA	NA	5 (including the BS)	By scientists	NA
10	IRIS motes	NA	NA	YES	NA	NA	NA	16	Placed in two sets of 8 motes each	YES
11	Mica2 + MDA300 sensor board Superlite for GW	Atmega 128	NA	NO	NA	EEPROM as backup	-Deacagon Echo-20dielectric sensors for soil moisture -Deacagon Echo rain gauge for rainfall sensor	NA	Placed as a tree branch	YES
12	TelosB motes	MSP430	CC2420	NO	NA	NA	-Sensirion SHT11 for T & H -Photodiode hamamatsu S1087 for illuminance -Voltage sensor -GE Telaire 6004 for CO2 content	150 for the indoor test bed 400 for the prototype	Random deployment	YES

								200+ for the Tianmu Mountain		
13	TinyNode + sensor interface board	TI MSP430	Semtech XW1205	NO	NA	External data storage flash memory SD card: 1GB RAM	-Sensor rod for profiling of T and electrical conductivity in solid rock -Thermistor chains T profiling inside cracks -Crack meters consisting of a linear potentiometer for movement measurements -Digital water pressure sensors to assess water flow in cracks -Analog earth pressure cells for assessing ice stress inside cracks -self potential sensors using analog differential conductivity measurements	20 nodes	The sensors that monitored inside of rock walls, were installed inside rods. Each rod contains 4 thermistors & 4 electrode pairs equidistantly spaced, while connected to a multiplexer inside the sensor rod. Each sensor rod is inserted into a 1m deep hole, drilled into the rock and attached to a sensor node mounted nearby. The sensor nodes were mounted to rocks. The installation of the nodes was	IP68

									conducted by the team members of the PermaSense project, after alpine safety training courses, which are continuous	
14	Mica2Dot for sensor nodes Stargate for GW	Atmel ATmega128 at 4 MHz	Chipcon at 433MHz	NO	NA	Flash: 512KB	-Sensiron SHT11 digital sensor for T& RH -2 Hamamatsu S1087 photodiodes for PAR	33	The nodes were installed on the tree, 15m from the ground with 2-meter spacing between the nodes	YES

Sensor node's sensing/sending data packets				Data transmission/communication	
Deployment's ID	**Time-based**	**Event-driven**	**Requirement-based**	**Single-hop**	**Multi-hop**
1	Once every min.			Weekly or every two weeks	
2	Once every half an hour	-	-	-	X
3	X	-	-		X
4	X	-	-	-	10min. -15min.
5	Every 4 hours for 15s sensing	-	-	Once a day for 3min	-
6	X	-	-	Every 15min	-
7	Sampling every 2 and half min.	-	-	-	X
8	-	Sampling rate of 3s	-	X	-
9	Dynamically adjustable sensing period	-	-	-	X
10	Every 10min.	-	-	X	-
11	-	Rainfall event	-	X	-
12	Once per minute	-	-	-	X
13	Every 2min	-	-	-	X
14	Once every 5min	-	-	-	X

WSN's Software			
Deployment's ID	**Protocols**	**Algorithms**	**Node OS**
1	Automatic Repeat reQuest (ARQ)	NA	Custom software based on TinyOS
2	Spanning Tree protocol (routing) TCP/IP TDMA	NA	TinyOS
3	MintRoute routing protocol	NA	TinyOS
4	Randomized channel hoping protocol Ethernet	Dynamic smart-meshing algorithms	NA
5	NA	NA	NA
6	NA	NA	TinyOS
7	Collect Tree protocol CTP (routing)	NA	TinyOS
8	NA	Delta compression	TinyOS
9	Surge routing protocol	Filtering algorithm	NA
10	ZigBee	NA	TinyOS 1.1
11	SMAC	NA	TinyOS
12	Collect Tree protocol CTP (routing)	NA	TinyOS
13	Dozer multi hop protocol	NA	TinyOS

14	MintRoute	NA	TinyOS

Network issues				
Deployment's ID	Satellite system	Wireless	Wired	Cellular
1	-	802.15.4 between motes and the mobile BS(laptop)		
2	-	RF Internet	-	GPRS connection between nodes & GPRS node
3	-	RF for the motes	-	GPRS module for nodes Independent GPRS for camera GSM text messages for remote management of the sink
4	-	RF between WSN nodes 802.15.4	Ethernet between BS and the low-power PC for exchanging commands	Wired GPRS modem positioned 25m up the tower
5	-	RF at 433MHz between probes-BS Long-range radio modem between BS-Reference Stn	BS transceivers (which are buried 30-40cm under the ice) are connected via serial(rs-232) cables ISDN dial-up connection between RStn and Southampton Server	GSM between BS – Reference Stn (in case of communication problem with the long-range radio)
6	-	RF between motes BS(attached to a laptop) and motes	-	-
7	-	Local sub-network between sensor patch and Gateway Local transit station between GW and BS Internet for BS	Receiver from area B with the BS in area C	-
8	-	RF between sensor nodes and BS User interaction through Web application(Internet)	BS connection to the Back End SubSystem through USB	-
9	-	Internet connection between BS and Server and for users to connect to Server	Or serial cable between BS-Server	-
10	-	ZigBee connection between motes and BS	RS232 between BS and GW and between Data logger and GW RS232 between GPRS modem and GW	GPRS modem
11	-	RF for motes	Serial cable between Base node and GW	GSM for GW GPRS for internet connection of GW
12	-	X	-	-
13	-	RF between BS and sensor network and between sensor nodes	-	GSM/GPRS connection from BS to the internet as backup
14	-	RF	-	GPRS

Power issues								
Deployment's ID	**Battery type**	**Battery capacity**	**Replacement frequency(if needed)**	**Expected battery lifetime**	**Solar panel**	**Solar panel capacity**	**Expected solar panel lifetime**	**Power saving/ management techniques**
1	2 AA	2200 mAh	N/A	NA	-	-	-	Sleep-wake up cycle for MCU and radio
2	1 Li-SOC12 for TinyNode nodes A set of Li-SOC12 for GPRS node	NA	N/A	4-5 years	-	-	-	-Source code changes for automatic power management Sleep-wake cycle
3	NiMH rechargeable as primary Li-Ion as secondary	150mAh 2200mAh	NO	NA	MSX-01F	NA	20 years	Power control driver Duty cycling technique
4	12 V Lead acid battery	7Ah	NO	NA	YES	10W	NA	Hibernation state for nodes
5	6 3.6V Lithium Thionyl Chloride cells for probe powering Lead-acid gel batteries connected in	NA for probes 96AH(1152WH)	NO	10 years (theoretically) 230 days	2 panels	15W	Additional 100 days	Sleep-wake up cycle

	parallel with solar panels for BS							
6	2 D-cell alkaline	14,000 mAh	Every 30 days except during winter 2006-2007 because of weather conditions	NA	-	-	-	Idle function
7	Batteries	NA	NA	NA	-	-	-	NA
8	NA	NA	NA	NA	-	-	-	Aggregation & compression
9	NA	NA	NA	NA	NA	NA	NA	NA
10	Lead-acid rechargeable for weather station devices	12Ah	NO	7 days with no recharging	A solar panel	NA	NA	Duty cycling of 15% Sleep-wake up mode
	2 NiMH for motes	2500mAh		4 weeks without recharging	Solar cells			
11	SAFT LiSO2	8000mAh	NA	30 days for rain mote 16 days for soil moisture and router motes	NO	-	-	Activity-sleep states
12	AC/USB/AA batteries for test bed	NA	NO	NA	NO	-	-	Duty cycling techniques
	D batteries for prototype	~8000mAh						
	D batteries for mountain forest	~8000mAh						

13	Li-SOCL2	NA	NA	NA	Solar cells for BS	NA	NA	Sleep-wake up cycle
14	X	NA	NA	NA	Solar panels	NA	NA	Duty cycling of 1.3%

WSN's Costs & Requirements					
Deployment's ID	**Average price per node**	**Operating cost**	**Maintenance cost**	**Qualified stuff requirements**	**Total cost**
1	1000 Euro (including operating & maintenance cost)	NA	NA	_	NA
2	NA	NA	NA	NA	NA
3	$900(the price includes the whole sensor station with solar panel, the sensor nodes with everything)	NA	NA	NA	NA
4	NA	NA	NA	NA	NA
5	177£	NA	NA	NA	1416£ (for probes)
6	200$ US	NA	NA	NA	NA
7	NA	NA	NA	NA	NA

8	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA
10	NA	NA	NA	NA	NA
11	NA	NA	NA	NA	NA
12	50$ US	NA	NA	NA	NA
13	$109	NA	NA	NA	NA
14	NA	NA	NA	NA	NA

Appendix C – Air-Water pollution deployments

General information about deployment Air-Water quality monitoring							
Deployment's ID	**Place of Deployment**	**Total project's/experiment's duration/chronology**	**Deployment landscape features**	**Monitoring subject**	**Measured factors**	**Topology/Architecture**	**Additional applications/observations**
13	3 Borehole wells in Landfill site in Ireland	16 months 2008-2010	-	Gas migration	-Humidity -T -CH_4(methane) -CO_2(carbon dioxide	Architecture: - 1 Gateway - 1 GSM BS - SQL Server PC - Web app. Single hop	The monitoring cycle of this deployment is consisted of 3 stages: - 3min. baseline - 3min. sample - 3min. purge The statistical of these stages are being sent to BS Sensor calibration in the lab prior to deployment
14	Laboratory experiments (APOLLO)	N/A	-	Air pollutants	-CO -NO_2 -PM(particulate matter) -VOCs(volatile organic compounds) -T RH	Tree-based Multi hop	Preliminary experiments were conducted to understand the characteristics of each gas sensor used Implementation of the system on a host PC application to provide sensing info to users to evaluate the performance of the system and to provide a pollution detection alarm
15	Environmental sensing chamber(ESC), Laboratory	N/A	2m x 1m x 1m dimensions, so the total volume is $2m^3$	Chemical plume acid	-Acetic acid plume	Star	The ESC is been developed for small scale(5-10 nodes) WSN's. The conditions inside the ESC are semi-realistic. There were important requirements to take under

							consideration while developing the ESC such as the air tightness.
16	St. Mary's Lake on the University of Notre Dame campus, USA	10 days in late October-early November 2005	10m from shore and occupy about 9m of water surface Water depth is no more than 1.3m	-	-T -PH -Dissolved oxygen	Multi hop topology	The gateway is connected to a laptop and the connection between GW and the pods is occurring once a day For major elements concentration characterization of the lake, samples were collected from a different site of the lake and was analyzed using a Perkin Elmer Optima 3380XL ICP-OES
17	Underground water table in a pump site Queensland, Australia	February 2007	About 2km x 3km Tropical area with sugar cane	-	-Salinity (μ/S/cm) -Water level(cm) -Flow volume(litter/s) -Flow rate(tick/s)	Dynamic & multi hop topology	For more robust system there were implemented watchdog logics at the sensor nodes & gateway The sensor network is sparse The hardware architecture relies much on the SPI bus With the link quality aware routing protocol(surge_reliable) the network stays in the same topology more than 70% of time Based on the observations, Surge reliable protocol does not function well in downstream(from nodes to sink) as it does in upstream The delivery rate per day, on

							average, was approximately about 66.33%
18	Lake Albufera, near the city of Valencia, Eastern Spain	7 days		-	-Nitrate -Ammonium -Chloride -Water T	Tree based System architecture: -Data acquisition sub-system which is formed by sensors -Control & communication sub-system, including the sensor network itself -Data management sub-system which is comprised of the Web server with DB	The web server can be accessed from any device (PC, Laptop, PDA, etc.) with appropriate permissions by means of digital certificates or a password. The web server is based on GNU software (Apache and MySQL) For access to the DB and parameters changes a GUI based on Web technologies has been developed, which also uses GIS system To evaluate the results from the WSN, water samples were taken on a daily basis and were compared with those obtained by the WSN

19	Broameadow Water Estuary Co. Dublin, Ireland	3 days since 4/9/2010	-	-	-Phosphate concentrations	-A sensor node within enclosure -A gateway -Web-DB	There were collected manual samples, which were analyzed in the Lab using a Hach-Lange DR890 Portable Colorimeter, to evaluate the samples taken from the sensor node The results from the correlation are almost excellent. The data from the sensor node are statistically represented and sent in sms format to a BS via GSM
20	10 borehole wells in a landfill site, North-East Ireland(Smart Landfill)	2 months February-March 2008	-	Landfill gas concentration s	-Humidity -T -CO_2 -CH_4(methane)	NA	Data are saved onto a Dell Notebook with the use of Hyperterminal There have been numerous successful field trials with Smart Landfill The data gathered from the WSN were correlated with the data gathered with the GA2000 unit for WSN results evaluation
21	2 deployments in the Lake Fulmor, CA, USA	In May & July of 2005 for 4 and 2 days respectively	N/A	-	-Chlorophyll-a concentration -T	-Static nodes -Robotic boat as a gateway and sensor node -BS	The fluorometer sensor provides a wide measurement dynamic range of 0.03 to 500 micrograms/l For battery recharging there can

						Multi hop, ad-hoc	be used ecternal solar panel The software of the system is EmStar There is a set of software tools for data retrieving & visualization, the tools of which are built with Matlab and Java The robotic boat can collect samples for biological analysis for high degree of spatial sampling The robotic boat operates in three modes, i.e. radio control mode, computer controlled mode and autonomous mode Initial field test were carried out at Shelter island, NY According to deployment's results, the robotic boat operated successfully combined with the static nodes as well as performed autonomous water sample collection at specified GPS locations
22	Derwent estuary in Southern Tasmania, Australia(TasMAN)	January 2009-	N/A	-	-T -Salinity -Depth	-Fixed & mobile nodes -Gateway -BS Cluster-based	The cluster provides with real time data of 10-15min The gateway node queries the riverbed nodes every 10min for data gathering The communications of the TasMAN include acknowledgments and some

							retransmissions The network also features a mobile node which can be used for data muling from the sensor nodes in case of communication fail The data from the data loggers is being retrieved every 3 months The TasMAN project is currently under deployment
23	Lake Wivenhoe near to the city of western Brisbane, Australia	N/A	$80km^2$ network coverage	-	-T	-Floating, static sensor nodes -A mobile node, Autonomous Surface Vehicle(ASV) as a GW as well -DB Ad hoc	Bright low-power strobes were used at night to prevent collisions with boats Field trials with ASV were conducted on Little Nerang Dam, in Brisbane All data format is in TDF The ASV included scanning laser rangefinder for obstacle detection and a depth sounder The extra sensor node that was on the ASV had a single T sensor which was at the depth of 50cm, as the floating nodes
24	Lake Perez, central Pennsylvania, US	2 days	The total lake's size is 72-acre with an average depth of 7.62m(25ft)	-	-T -pH	-1 Host node -1Uplink node -3 Sensor nodes -Central PC Multi hop	The microcontroller is programmed with AVR 8-bit RISC machine language The host node initialize the network operation sending broadcast message to the uplink node, which in turn send his

							message to the sensor nodes to establish communication links The host computer software is programmed with Microsoft Visual Basic This particular project is designed for long-term monitoring but in this case the test was limited to 2 days There is way to increase battery lifetime, of course, by adopting sleep-wake up mode, which will give at least 2 months lifetime
25	A sandbank called Scroby Sands, off the coast of Great Yarmouth in Eastern England, UK	Over 2 weeks in October 2004	N/A	Water quality	-T -Water pressure -Turbidity -Salinity Current velocity	- Buoys Sensor nodes -Reporting station Star topology	For this deployment the scientists had to get license from Marine Consents & Environment Unit(MCEU), radio license from OFCOM and from Crown Estate for equipment installation on coastal seabed The deployment place, i.e. near the shore, was south of the windfarm, which is consisting of 30 large turbines The general behavior of the sensor modules was as expected

26	Frozen lake in Zackenberg, Greenland(MANA)	August 2008- August 2009	N/A	-	-Salinity -T -Depth -Dissolved oxygen -Chlorophyll -Turbidity	-Buoy as a sensor node -BS Tiered sensor network	The buoy uses WET Lab's Water Quality Monitor(WQM) which contains the mentioned sensors. Also the WQM functions as a data logger The only way to reach this lake and to carry the heavy equipment is by helicopter, which is expensive, i.e. a 30min flight costs US$4000! The data were obtained during the second season that is in 2009, because of system failure, which is reasonable under harsh circumstances
27	Artificial lake at HnagZhou DianZi Univercity, China	About 1 month, November 2008	N/A	-	-T -pH	Ad-hoc, multi hop consisting of sensor nodes, a BS, a GPRS GW and a remote center	The development environment for sensor nodes software is IAR Embedded Workbench and C programming language The BS's operating system is the µC/OS-II embedded OS The remote monitoring center consists of the GPRS GW and the data center

WSN Hardware										
Deployment's ID	Node platform	Microcontroller	Radio transceiver	GPS	Radio antenna	Memory type/ size of a node	Sensor	No of nodes	Installation issues	Protective case
13	PCB by Beta Layout Ltd	MSP430F449	-	NO	-	2 Mbit flash	-Honeywell HIH-4000-001 humidity sensor -Thermistor Thermometrics DKF103N5 temp. sensor -Non-dispersive infrared(NDIR) based CH_4 and CO_2 sensors	3 gateway nodes(one for every deployment site)	Placed in borehole wells	YES
14	IEEE802.15.4-based sensor node	MSP430	TI CC2420 at 2.4GHz	NO	N/A	N/A	-MiCS-5521 heating semiconductor for CO -MiCS-2710 heating semiconductor for NO_2 -MiCS5135 heating semiconductor for VOC -PPD4NS LED for PM -D-120 NDIR for CO_2 -SHT11 Sensirion CMOSens for T	2(one in each of two experiments)	One node in an non-polluted controlled atmosphere One in a polluted atmosphere	NO
15	MPR500Mica2 Dot + MTS510A sensor board for sensor nodes And MPR400 Mica2	N/A	N/A	NO	N/A	N/A	-LED based chemical sensor -3mm LED as indicator for sensor threshold crossing	5	1-4 sensors were arranged in ascending order near the acetic acid channel input while the 5th sensor positioned outside	YES

	+ MIB510CA serial interface board for BS								the channel	
16	Mica2 + MDA300 data acquisition board	N/A	N/A	NO	N/A	N/A	N/A	8 + 1 gateway	The pods were deployed in two rows, 1m apart from each row and the pods are 2m apart from each other	YES
17	Fleck 3 for sensor nodes ARM-based board for gateway	Atmel Atmega 128 for Fleck	NRF905 with transmission range up to 1500m(Fleck)	NO	N/A	RAM: 4Kbytes Flash: 1MByte	-Electrical conductivity (EC) by Toroidal Conductivity Sensor TCS1000 for salinity -Depth of the water by a PS100 pressure sensor -Electromagnetic flow meters for flow volume & rate	8(including gateway)	The flow meters and the EC sensors were mounted in the pipe connecting the pump to the reservoir tank, while the pressure sensor was mounted in an observation bore.	YES
18	N/A	ARM9 for sink node	CC1101 for sink	NO	N/A	N/A	Ion Selective Electrodes (ISE's) sensors for the chemical elements	14 buoys which contain a sensor node each	Fixed installation	YES

19	N/A	MSP430	N/A	NO	N/A	Onboard flash memory chip for backup purpose	IR gas sensors: - IRCEL-CO_2 - IRCEL-CH_4	1 system includin g sensor node	In situ placement to estuarine water body	32 YES
20	N/A	MSP430F449	N/A	NO	N/A	2Mbit onboard flash memory chip	-IRCEL-CO_2 -IRCEL-CH_4 -Thermistor DKF103N5 for T -Radionics 525-43171 for humidity	NA	Smart landfill units were installed in the boreholes	YES
21	Stargate in which an ADC board is connected serially or through USB	Intel 400MHz Xscale PXA255 for Stargate & BS2sx for ADC	N/A	NO	External antennas	N/A	-CYCLOPS-7 submersible fluorometer -Therrmistor sensor	5 static nodes + robotic boat	Static nodes are scattered in the lake's surface and the robotic boat is moving in the range of WSN The fluorometer is installed at 1m above the water surface while the thermistors are uniformly at depths ranging from 0.5m to 2.5m	YES
22	Fleck^{tm}	N/A	N/A	NO	High-gain 7 dBi	N/A	N/A	6 nodes(of which 2 are data loggers)	The three-node cluster with the GW is placed at he eastern site of the mouth of the estuary, the 2 of which are sensor nodes at the riverbed and the GW node at	YES

									surface, two nodes(data loggers) placed at the western side of the mouth and a single node is near to the research center(CSIRO) in Hobart	
23	Fleck^{tm}	N/A	Nordic NRF905 at 915 MHz	YES	High-gain 6dB	N/A	-Maxim DS28EA00 digital thermometer	50 floating nodes + 1 ASV	The floating sensor nodes and the ASV are installed at the surface of the lake	YES
24	N/A	Atmel AT90S8535	N/A	NO	N/A	ROM: 8kB	-Thermistor sensors for T -pH Probe Model 760	5 (of which 3 are submerged under water, one is floating and one is out of the water)	The submerged nodes were installed under 2m depth using anchors and the distance between them varied from 80m to 100m. The host node was placed in a building about 300m from the uplink node.	YES
25	N/A	MIC	Radio frequency at 173.25 MHz	NO	N/A	N/A	-T sensor -Water pressure sensor -Optical backscatter sensor for turbidity -Electrical conductivity sensor for salinity	6	Deployment was carried out parallel to the direction of the tidal current and the locations were chosen to be close to sandbank in shallow water. 6 buoys installed on the surface of	YES

									the water and the sensors on them placed at depths of 6m fot 5 buoys at around 10-12m for the 6th one, all stabled with weights	
26	Arch Rock IPserial for the node Vexcel microserver for BS	N/A	N/A	YES	Omni directional for the buoy and directional for the BS Wi-Fi, sensor network and GPS antennas on the top of the pole with the solar panel on it	N/A	N/A	1 buoy and 1 BS	For installation there was used an anchored buoy and the sensors were positioned at 2 beneath the surface The BS installed at the shore	YES
27	N/A	MSP430F1611	CC2420 at 2.4GHz for sensor nodes CC2430 for BS	NO	N/A	For BS AT45DB081D SRAM: 8K Flash: 64K	-LE-438 sensor for pH and T	5 sensor nodes + 1BS	The sensor nodes are placed, in a waterproof floating cabin, on the water surface with an anchor for stability. The sensor are in the water outside of the cabin	YES

Robotic vehicle use							
Deployment's ID	**Vehicle type**	**Board platform**	**GPS**	**Compass**	**Sensors**	**Communication**	**Power supply**
21	Modified RC airboat	Same with the static node	Garmin 16A	V2XE 2-axis digital	Same with the static node	802.11b wireless connection with nodes Wi-Fi	Rechargeable NiMH
23	A 16ft twin-full surface vehicle	Onboard computer Pentium M 1.4GHz and Fleck gateway which is serially connected with the computer	YES	YES	-Water T	Communication with the GW is being done through serial port Wi-Fi	2 large solar panels

Sensor node's sensing/sending data packets				Data transmission/communication	
Deployment's ID	Time-based	Event-driven	Requirement-based	Single-hop	Multi-hop
13	Two times a day and after March 2010 4 times	-	-	X	-
14	X	-	-	-	X
15	Every 150ms	-	-	X	-
16	Every min	-	-	-	X
17	X	-	-	-	X
18	Every hour	-	-	X	-
19	Every 30min	-	-	X	-
20	One sample per day	-	-	X	-
21	X	-	-	-	X
22	Every 10min	-	-	-	X
23	Sampling & sending Temp. data every min. and engineering data(battery voltage, etc.) every 5 min. The ASV sample and send data every 10s	-	-	-	X
24	Sampling every 6s	-	-	-	X
25	X	-	-	X	-
26	X	-	-	X	-
27	Once every other hour	-	-	-	X

WSN's Software			
Deployment's ID	Protocols	Algorithms	Node OS
13	N/A	Software processing algorithm	N/A
14	CSMA/CA communications MAC protocol	Correction algorithms were applied to sensor board	Retos kernelOS
15	N/A	N/A	N/A
16	N/A	N/A	N/A
17	Surge_Reliable multi hop routing protocol for the network layer CSMA in the MAC layer NACK and ACK protocols in the transport layer TCP	N/A	TinyOS for Fleck3 Linux for the gateway
18	Routing Tree-based protocol (RTP) TCP/IP HTTPS	N/A	N/A
19	ZigBee Two-point calibration protocol	N/A	N/A
20	NA	N/A	N/A
21	Multi hop protocol 802.11b protocol	N/A	N/A
22	NA	N/A	Fleck OS(FOS)
23	CTP	N/A	FOS for static nodes Linux for mobile node
24	RS232 protocol	N/A	N/A
25	N/A	Node management algorithms Lightweight device control algorithm	N/A
26	6LoWPAN	N/A	N/A

27	ZigBee	Shortest Path First algorithm	N/A

Network issues				
Deployment's ID	Satellite system	Wireless	Wired	Cellular
13	-	Bluetooth for short-range communication	-	GSM for remote communication in sms form
14	-	X	-	-
15	-	X	-	-
16	-	X	-	-
17	-	RF between sensor nodes	Gateway connection to the internet using ADSL modem	-
18	-	Private Wireless Network between nodes and the sink node	-	Public Wireless Network GPRS between sink node and data management system
19	-	ZigBee radio between the node and the gateway Wi-Fi between gateway and Web DB	-	GSM between gateway and Web DB
20	-	Bluetooth between sensor nodes and BS	-	-
21	-	802.11b for inter-node communication RF between robotic boat and BS	-	-
22	-	Acoustic communication between cluster nodes	Inductive communication between sensor nodes and GW	3G link between gateway and the DB server
23	-	RF between nodes	-	-
24	-	Acoustic waves for node-to-node and for node-to-uplink node communication and vice-versa RF for uplink node-to-host node and vice-versa	RS232 connection between host node and a PC	-
25	-	RF between nodes and the cluster	-	-

26	-	802.15.4 between buoy and BS Wi-Fi	-	-
27	-	ZigBee between sensor nodes and BS	-	GPRS between BS and remote monitoring center

Power issues						
Deployment's ID	Battery type	Battery capacity	Battery estimated lifetime	Battery replacement (if needed) frequency	Other forms of power supply	Power saving/management techniques
13	Main rechargeable, high capacity 12V battery 2 AAA for microcontroller uninterrupted power	N/A		Main battery	3V3 & 5V regulators External waterproof switch for blue tooth module power Standard 12V power adapter(Masterplug MVA1200-MP) for BS	Wake up/Low power mode
14	12V Li-ion rechargeable	N/A		N/A	Power outlets for sensor board power supply	Electrical switches for gas sensors
15	CR2354 3V Li-ion coin cells	N/A		N/A	-	N/A
16	2 D cell for each pod 12V marine battery for the 3 sensors	N/A		-	-	Sensor interface board to turn the sensor probes off between sampling intervals
17	NA	N/A		N/A	N/A	N/A
18	Li-ion rechargeable	10W		-	-Solar panel 50mm x 70mm -UPS for the data management sub-system server	Intelligent system RTC(Real-time clock) for energy management
19	12V lead acid	5Ah		-	-	N/A
20	12V lead acid	7Ah		N/A	-	N/A
21	Car battery for static	N/A		-	-	N/A

	nodes					
22	9V Alkaline cells	120Ah		Every three months	-	N/A
23	Solar cells floating for nodes	N/A		N/A	Solar panels for ASV	N/A
24	4 NiMH	1800mAh	With continuous operation can last for 53h	-	-	-
25	2 alkaline D-cells	N/A	N/A	N/A	-	N/A
26	6V Exide batteries	N/A	N/A	-	Solar panel on top of a 2.5m pole	Waterproof switch which can be turned of during transportation without using power
27	7.2V 6 nickel-hydrogen or 7.4V 2 lithium for nodes 7.2V 6 NiMH or 7.4V lithium as external power source for BS	N/A	N/A	N/A	-	LM2596 and TPS79533 power chips

WSN cost/maintenance			
Deployment's ID	Average price per node	Total cost	Maintenance tasks
13	N/A	N/A	System check, cleaning and spray silicone applying to PCB boards in the lab
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	N/A	N/A	N/A
17	N/A	N/A	N/A
18	N/A	N/A	The probes with the ISE's sensors were cleaned with distilled water and soft paper before being placed in the lake
19	<200 Euro	N/A	N/A
20	N/A	N/A	N/A
21	N/A	N/A	N/A
22	N/A	N/A	Every three months
23	N/A	N/A	N/A

24	N/A	N/A	N/A
25	Around 1200 Euro (£1000)	N/A	N/A
26	N/A	N/A	Anti-biofouling mechanism that provides maintenance to the sensor node, without the need of scientists visit
27	N/A	N/A	N/A

Appendix D – Destruction Phenomena deployments

Volcanoes - Flooding

General information about deployment Volcanoes- Flooding						
Deployment's ID	**Place of Deployment**	**Total project's/experiment's duration/chronology**	**Deployment's landscape features (size, elevation, vegetation, climate, etc.)**	**Measured factors**	**Topology/Architecture**	**Additional applications/observations**
31	Volcano Mount St. Helens trial deployment, Washington, US	Since October 15th for over 1.5 months in 2008	Crater diameter around 1mile Rugged terrain and reachable by helicopter	-Motion of the ground -Low frequency acoustic waves -Lighting strikes detection -Ground deformation	Multi –hop -Sensor nodes inside stations -Sink node -Gateway(MOXA) -Server	For temporal & spatial correlation of the volcano signals, the earth scientists required that all stations perform synchronized sampling, so an RTC(Real Time Clock) module was designed The sampling rate and sensing other parameters must be adjustable, based on environmental conditions and mission needs There was developed a transparent and light-weighted RPC(Remote Procedure Call) mechanism to support remote visibility into network failure The network was also enabled to report periodically important events or node status for network health diagnosis, such as battery voltage, buffer status and RSSI & LQI Prior to real deployment in the volcano, the system was deployed on the university campus for 3 months

						The WSN supports network management and manipulation tools (VALVE server, V-alarm, etc.) The data extracted from the deployment, area, is stored in a MySQL DB The end-to-end data delivery ratio is 91.7%, which includes the different kind of failures during this 1.5 month deployment During the deployment, which was an evaluation period, the system managed to recover from many challenges without any dead node Volcano data evaluation was conducted by comparing it with the other data sources from the volcano
32	Volcano Mount St. Helens, Washington, US	On July 2009	Crater diameter around 1mile Rugged terrain and reachable by helicopter	-Ground deformation -Earthquakes -Volcanic explosions -Eruption clouds	Multi hop topology Network architecture: -Sensor nodes -Sink node -Gateway -WSUV server in lab, which forwards the real-time data to the Internet	The WSN is designed to operate unattended for an entire year The WSN supports network management and manipulation tools (VALVE server, V-alarm, etc.) The sensor network is comprised of 2 branches, where each of these branches operates with separate data collection sink and radio channel

33	Active volcano Reventador near to capital Quito, Northern Ecuador	19 days between August 9th-19th, 2005	Volcano's height is reaching 3500m Its temperatures are ranging between 10-30C^{o}	-Earthquakes -Volcanic explosions	Multi hop routing tree topology -Sensor nodes -Gateway node -BS about 4km away -Freewave modems -Additional nodes	Each node transmits a status message every 10sec and includes it's position, battery voltage, etc. Data is stored in flash, which is treated as circular buffer, as 256-byte blocks and each block is tagged with local timestamp The volcano included also 2 standalone seismic stations, consisting of a broadband sensor, Reftek 130 data logger with 1 GByte flash and a GPS receiver, that were collocated with the WSN The network was installed in two phases of 8 nodes each, the first in August 1st while the second in August 3rd Two Micaz nodes were used in supporting roles There are three relevant timebases: the local time at each node, the global by FTSP protocol and the GPS time The network faced synchronization losses and some other problems but in general the system's performance was satisfactory as the retrieved data was from 61% of the network and the event-trigger model worked well

34	Volcano Tungurahua, central Ecuador	From July 20-22, 2004	The terrain is steep with large amount if vegetation	-Volcanic activity	Multi hop topology Architecture: -Infrasound nodes -Aggregator nodes -GPS receiver node -2 Freewave modems -Wired laptop as BS	25 data continuous packets were packed into a 32-byte radio packet and transmitted at 4Hz The loss rate for each node varied during the deployment due to weather conditions affecting radio transmission The sensor network was collocated with a wired seismic and infrasound station, so these data were compared with those of the WSN for evaluation Two local event detectors were implemented, which are threshold-based detector and exponentially weighted moving average(EWMA)-based detector
35	Upper Charles River at Dover, Massachusetts, US	October-November of 2007	-	-Rainfall -Air T -Water pressure	Single hop	The network was tested using data ser of real river, Blue River in Oclahoma, also was tested in Honduras, central America

WSN Hardware											
Deployment ID	**Node platform**	**Microcontroller**	**Radio transceiver**	**GPS**	**Radio antenna**	**Memory type/ size of a node**	**Sensor**	**No of nodes**	**Station design and components**	**Installation issues**	**Protective case**
31	iMote2 + MDA320 CA sensor board	PXA271	CC2420	YES	Omni directional 6dBi	SRAM: 256KB SDRAM: 32MB	-Seismic sensor Model 1221J-002 -Infrasonic Model 1 INCH-D-MV pressure sensor -Lighting sensor an RF pulse detector for lighting strikes -U-Blox LEA-4T L1 GPS	5 stations	A 3-leg spider, about 4-foot tall, that includes an antenna and weights about 31.7 kg (70 pounds) Components are encapsulated in a weather proof iron box, that includes an iMote2, an acquisition board, a GPS receiver and expansion connectors	The installation of the stations was air-dropped into the crater within an hour	YES
32	iMote2	PXA271	CC2591	YES	N/A	N/A	-2 types of seismometers: low cost MEMS accelerometer and geophone sensor (Geospace HS-1) - U-Blox LEA-4T L1 GPS for ground deformation -Infrasonic Model 1 INCH-D-MV pressure sensor - Lighting sensor for volcanic activity monitoring	13	The same as previous deployment	The installation of the stations was air-dropped into the crater From the 2 network branches, one is placed inside the crater with 6 nodes and the other one is placed around the flank forming a semicircle	YES

33	Tmote Sky for sensor nodes Micaz for additional nodes	TI MSP430	CC2420	YES	8.5 dBi external omni directional antenna	SRAM: 10KB ROM: 48KB Flash: 1MByte	-Seismometers in single axis and triaxial configuration GeoSpace GS-11 & 1 -Omnidirectional microphones Panasonic WM-034BY	16	It is consisting of a sensor node, an 8 dBi omnidirectional antenna, a seismometer, a microphone and a custom hardware interface board	The 16 sensor nodes were placed with hands, on the upper flanks of the volcano, over a 3km linear configuration	YES
34	Mica2 + custom sensor noard	ATmega128L at 7.3MHz	CC1000 at 433MHz	YES	A pair of 9dBi 900MHz Yagi antennas for modems	4KB	Infrasound sensors connected to a Panasonic WM-034BY omnidirectional electrets condenser mic	3 infrasound nodes and 1 aggregator	Is consisted of a custom sensor node with an amplifier and filtering circuit connected to the mic and a n antenna	The aggregator node, GPS receiver, modem Yagi antenna and car battery were placed at the foot of a tree. One of the sensor nodes was placed 1m above the ground in the same tree, another was placed 6.3m in a second tree and the third one was installed 10.7m away on a tree stump	YES
35	N/A	ARM7TDMI-S specifically the LPC2148	N/A	NO	High gain	Mini-SD card FRAM	N/A	3	-	The nodes were placed across the river	YES

Sensor node's sensing/sending data packets					Data transmission/communication	
Deployment's ID	**Time-based**	**Event-driven**	**Requirement-based**	**Sampling rate (Hz)**	**Single-hop**	**Multi-hop**
31	-	X	-	Dynamic sampling, that is if an event will be detected, the sampling rate will get higher -Seismic & infrasonic sensors sample at 100 Hz with 16-bit resolution -Lighting sensor at 10Hz with 16-bit resolution	-	X
32	-	X	-	Dynamic sampling, that is if an event will be detected, the sampling rate will get higher	-	X
33	-	X	-	During normal operation, the seismic & acoustic sensors sample at 100Hz	-	X
34	-	X	-	Continuous data sampling at 102.4 Hz	X	-
35	Measurement every 5min and transmission every 10min	-	-	-	X	-

WSN's Software			
Deployment's ID	**Protocols**	**Algorithms**	**Node OS**
31	Z-SYNC hybrid time sync protocol that combines GPS & FSTP merits MultihopOasis data collection routing protocol Cascades data dissemination protocol TCP/IP	STA/LTA(short term average over long term average) algorithm	TinyOS
32	Cascades data dissemination protocol Deluge protocol Reliable Data Transfer(RDT) protocol TreeMAC protocol	STA/LTA algorithm Tiny-Dynamic Weighted Fair Queueing (Tiny-DWFQ) algorithm Adaptive Linear Filtering Compression(ALFC) algorithm	TinyOS
33	Deluge protocol Flooding protocol Fetch bulk-transfer protocol FTSP	MintRoute algorithm Event detection algorithm	TinyOS
34	Time synchronization protocol	N/A	TinyOS
35	N/A	N/A	Custom base software package developed in C

Network issues				
Deployment's ID	**Satellite system**	**Wireless**	**Wired**	**Cellular**
31	-	802.15.4 between stations, sink node and gateway Microwave Ethernet link between GW and Lab	-	-
32	-	Same as the previous	-	-
33	-	RF between nodes and nodes-GW Freewave radio modem for long-distance communication between GW-BS	-	-
34	-	RF from nodes to the aggregator From aggregator to BS via long distance radio modem	-	-
35	-	RF at 900MHz and 144 MHz	-	-

Power issues						
Deployment's ID	**Battery type**	**Battery capacity**	**Battery estimated lifetime**	**Battery replacement (if needed) frequency**	**Other forms of power supply**	**Power saving/management techniques**
31	Heavy Air-Alkaline	N/A	N/A	N/A	-	N/A
32	3V Air-Alkaline	1200Ah	400 days	-	-	If a there is a problem with a sensor or the hardware interface is disconnected, then its channel can be turned off to save energy and bandwidth
33	A pair of D-cell for each node Rechargeable car batteries for modems	N/A	N/A	During 3-week deployment, batteries were changed twice	Solar panels for car battery charging A diesel generator as backup power supply for the BS	N/A
34	2 AA for sensor nodes & aggregator 12V car battery for GPS receiver & modem	N/A	N/A	-	-	N/A
35	3.7V rechargeable lithium-polymer Lead acid	N/A	N/A	N/A	Photovoltaic panels	N/A

WSN cost/maintenance			
Deployment's ID	**Average price per station node**	**Total cost/Estimated total cost**	**Maintenance tasks/cost**
31	More than $2K(which includes GPS, infrasonic and lighting, except seismic sensors)	N/A	Low maintenance cost due to network's self-organizing and self-healing status
32	$3000(including radios & other sensors)	N/A	Low maintenance cost due to network's self-organizing and self-healing status
33	N/A	N/A	YES
34	N/A	N/A	N/A
35	N/A	N/A	N/A

Landslide deployments

General information about deployment Landslide detection						
Deployment's ID	Place of Deployment	Total project's/experiment's duration/chronology	Deployment's landscape features (size, elevation, vegetation, climate, etc.)	Monitoring subject	Topology/Architecture	Additional applications/observations
36	Laboratory testbed	N/A	-	Landslides	2-level hierarchical architecture -Sensor nodes -Aggregators -BSs	Every 45min each sensor node sends status info to its nearest BS including BVR coordinates, energy level and a list of its neighboring nodes To deal with errors and failures the TelosB mote includes watchdog timer, which is enabled, to reset the nodes every 3 hours Data received at a BS, is synchronously replicated to other BSs The sensor nodes conduct some form of computation so the relied data to aggregators is consisting of the results of row data, called summaries Strain data from rock specimens were loaded into the external In addition to the WSN, the motes were also connected to a wired USB backbone network for software downloading, status info, etc.

37	Southern state of Kerala, India	N/A	Steep slopes, heavy rainfall and frequent landslide	Landslides	Two-layer hierarchy: Lower level -sensor nodes Upper level -aggregators -Gateway -Field Management Center -Data Management Center(DMC) consisted of DB server and analysis station	Power circuits were used to provide constant power & powering the interfacing circuits The sensor are connected with the MicaZ mote through data acquisition board The distance between the sensor columns is about 50m, at a slope of about 70^o Due to terrain structure and vegetation the sensed data is not able to reach the GW and for that there are 3 relay nodes Data received at the DMC are being analyzed using landslide modeling & visualization software, of which there is a probability of landslide detection
38	Hills with landslide potential	N/A	-	-	Multi hop grid topology Consisting of: -sensor columns -Gateway -BS	Detection of landslide event is performed through a 3-state algorithm which includes detection of small movements, self-localization of the moved sensors and calculation of their displacements and finally, estimation of position of the slip surface based on the previous phase

WSN Hardware										
Deployment ID	Node platform	Microcontroller	Radio transceiver	GPS	Radio antenna	Memory type/ size of a node	Sensors	Sensor column	No of nodes/columns	Installation issues
36	Mica TelosB	N/A	CC2420	NO	N/A	RAM: 10KB External flash: 1MB	-	-	65	-
37	Micaz	N/A	N/A	NO	N/A	RAM: 64MB Flash: 32MB	-Pore pressure sensors -Dielectric moisture sensors -Geophone -Tilt meters sensors -Strain gauges sensors for capturing earth movement	It is consisted of two components: sensor component containing all the sensors that is located below ground and the computing one which is above ground and contains the processor and the radio module	2 columns and 6 sensor nodes	One of the columns is placed at the toe region, near water lines and includes2 pore pressures at 2 and 5m depth, a moisture sensor The other one is located in an unstable region and is attached with 3tilt meters at 1, 2 and 3.5m depth as well as 3 strain gauges at 1.5, 2.5 and 4m depth. There is also a moisture sensor at 0.30m(1feet)
38	Stargate	N/A	N/A	NO	N/A	N/A	-Geophones -Strain gages -Pore pressure transducers -Reflectometers	Same with the previous	N/A	The sensor columns are placed inside drilled vertical holes and arranged on a semi-regular grid. The strain gages are placed on the surface of the tube along its vertical axis. Pore pressure sensors and reflectometers are placed at different depths at each column, while are installed on

										the outer hull of the column at regular intervals

Sensor node's sensing/sending data packets				Data transmission/communication	
Deployment's ID	Time-based	Event-driven	Requirement-based	Single-hop	Multi-hop
36	Once per 15min for ~4min	-	-	-	X
37	Sensor measurements every 5min except of geophone that sampled 10samples/s	-	-	X	-
38	X	-	-	-	X

WSN's Software			
Deployment ID	Protocols	Algorithms	Node OS
36	Beacon Vector Routing (BVR) protocol 802.15.4	Prediction algorithms: threshold-based prediction and Distributed Statistical Detection Energy conservation and fault-tolerance algorithms Aggregator selection algorithm	MantisOS
37	TCP/IP UDP 802.11b ZigBee	Threshold-based algorithm	N/A
38	N/A	Localization algorithm Landslide prediction algorithm	N/A

Network issues				
Deployment's ID	Satellite system	Wireless	Wired	Cellular
36	-	RF for nodes Wi-Fi for BS	-	GPRS
37	VSAT for long distant data transmission	RF between nodes and sink node Wi-Fi between GW-FMC	-	-
38	-	RF	-	-

Power issues						
Deployment's ID	Battery type	Battery capacity	Battery estimated lifetime	Battery replacement (if needed) frequency	Other forms of power supply	Power saving/management techniques
36	X	1800mAh	N/A	N/A	N/A	Algorithms Duty cycling and sleep-wake up schedule
37	Lead acid	N/A	N/A	N/A	Solar unit	Voltage regulator Negative voltage converter
38	Rechargeable	N/A	N/A	N/A	Solar panels	Sleep mode of the instruments(except for strain gages) Also no measurements are being sent until there a slip surface is confirmed

WSN cost/maintenance			
Deployment’s ID	**Average price per station node**	**Total cost/Estimated total cost**	**Maintenance tasks/cost**
36	N/A	N/A	-
37	N/A	N/A	N/A
38	N/A	N/A	N/A

Wild fire deployments

General information about deployment Wild land fires						
Deployment ID	**Place of Deployment**	**Total project duration/chronology**	**Deployment landscape features**	**Measured factors**	**Topology/Architecture**	**Additional applications/observations**
27	Rural environment in "El Encin", Alcala de Henares, Madrid, Spain	NA	2km diameter circle The agricultural area has different types of cultivation, vegetables, grapevines, many other types of plants and trees with great fauna & flora variety	-Smoke -Fire infrared radiation	Mesh network -IP cameras -Multisensors (which are fixed) -Access points	The position of the multisensors is saved in the server, but it could be changed at any time, that is there can be implemented mobile sensors, which can be monitored using GPS or wireless positioning-based systems Also there can be used other types of sensors to for more information, like temperature, humidity and CO_2 Last but not least, this deployment is for forested area monitoring as well
28	Bitterroot National Forest at Hells Half Acre, Kit Carson and Spot Mountain areas, Idaho, US	1 week	Wide range of elevations, mountainous & forested terrain	-T -RH -Wind direction & speed	Tiered architecture consisted of sensor nodes, a webcams, a BS and a central office (base camp)	The system had to be portable because the fires last for between 2-8 weeks. The members of the deployment team was trained in wild land fire and received certification to be authorized to work in a wild land fire environment The data that was gathered in the BS was stored in text files According to the results, there were some problems during the deployment. These were related BS problems and faulty data and dead batteries There was observed topology changes at the Kit Carson deployment There was used a hand-held GPS unit, because of

						nodes immobility, to record the location of the nodes The average distance between the nodes is 138m, with the longest nearly 393m
29	Campus of Moscow Aviation Technological University, Russia	October 2009	-	-Gas -Gas composition -Gas concentration	The system is consisting of two modules: gas sensor & energy scavenging module(ESM) Architecture: -gas sensor module -ESV -lap top as host	The ESM is designed in such that only one of the three energy sources can be used Prior to deployment the user must specify the type of the ambient source that will be used, using "jumpers" There was applied passive balancing to the capacitors to maintain similar voltage The batteries are charged by the primary power source, that is AC/ DC or capacitors Also there is a mechanism, Single Pole Double Throw (SPDT) for choosing which power source, primary or secondary, will supply the wireless sensor network For the ESM evaluation, there were conducted three experiments indoor and outdoor The emulation in the field test conducted using methane leakage or generating pyrolysis by setting a piece of wood on fire According to the members of this deployment, the system is able to detect fire before even smoke formation
30	Point Pinole Regional Park field tests, near San Pablo CA, US	September 16^{th} the 1^{st} filed trial & September 30^{th} the 2^{nd} one 2004	Grassy area	-Barometric Pressure -Embedded T sensor for checking external T values -T -RH -Location	-Sensor nodes -BS -Web & data server	The field tests were conducted with prescribed fires During the field test and for practical purposes, the BS, the DB server and client were operated from a single, day-light readable Fujitsu tablet personal computer The field tests were performed to investigate the proof of concept of the system and the robustness of the hardware under real wild fire conditions

WSN Hardware											
Deployment ID	**Node platform**	**Microcontroller**	**Radio transceiver**	**GPS**	**Radio antenna**	**Memory type/ size of a node**	**Sensor**	**No of nodes**	**Camera**	**Installation issues**	**Protective case**
27	Linksys WRT54GL + custom sensor board for sensor nodes Cisco Aironet 350 Series Wireless Bridges for access points	NA	Frequencies between 2412MHz-2472MHZ	NO	-Omni directional 20dBi for access points -Yagi antennas 12dBi for IP cameras - Omni directional 7dBi for sensors	RAM Flash SD card: 1GB	NA	NA	-MPEG-4 standard video compression Resolution: 320x240 using 24fps -Audio in both directions (from and to the camera) -The video streaming is transmitted directly to the server -The cameras are on all the time without going to idle state, thus consuming more power -Cameras settings (e.g. point of view) are managed by a person in the server -The wireless cameras can rotate 270^o horizontally and 90^o vertically	The installation occurred after studying the deployment area and the area coverage by the cameras, sensors and access points under areas circumstances. The multisensors are distributed strategically around the area but located inside the coverage area of an access point, same as cameras	YES

28	Mica2 for sensor nodes + MTS101 Basic Sensor Node Soekris net4801 for BS node	Atmel ATMega128 at 7.37MHz	Chipcon CC1000 at 900MHz	NO	Polarized directional antennas External Yagi for longer communication distance	NA SDRAM: 32Mbyte	-TSI 44006 for the embedded T sensor -Humirel 1520 for RH -Davis Standard anemometer for wind direction & speed	13 sensor nodes in total of which: 6 set up at Hells Half, 5 at Kit Carson and 2 at Spot Mountain + 1 webcams	2 different webcams were tested, which are Sony SNC-RZ30N and Panasonic KX-HCM280 They were set up in a protective case and were connected to an Ethernet switch for operation The webcams ran their own web servers allowing users to connect independently to it Webcams controls and configuration were accessible through the web interface and camera could rotate 360 degrees horizontally and 180 degrees vertically The Panasonic provided a picture resolution of 640x480, while the Sony 736x480 and both cameras provided infra-red night vision. The video was delivered at up to 30fps	The network installation was conducted by people with minimal experience in using sensor nodes The system was consisted of 3 sensor networks in 3 different areas The nodes were placed sufficiently near to fires of interest but not so near to avoid equipment losses The T & RH sensors were located inside the enclosure, while the anemometer was mounted outside of the node	YES
29	N/A	MCU ADuC836	N/A	NO	N/A	Flash/EE	N/A	1 gas sensor	-	-	N/A

Sensor node’s sensing/sending data packets				Data transmission/communication	
Deployment’s ID	**Time-based**	**Event-driven**	**Requirement-based**	**Single-hop**	**Multi-hop**
27	X	-	-	-	X
28	Every 14min for 1min	-	-	In the Spot Mountain	X
29	Every 15min	-	-	X	-
30	X	-	-	-	X

WSN's Software			
Deployment's ID	**Protocols**	**Algorithms**	**Node OS**
27	HTTP for video streaming	MPEG4 compression algorithm	Linux kernel 2.4
28	CSMA Network Time Protocol(NTP) 802.11 TCP/IP	Flooding algorithm	MantisOS for sensor nodes Version of Gentoo LinuxOS
29	NA	Power Management (PM) algorithm	NA
30	N/A	N/A	TinyOS

Network issues				
Deployment's ID	**Satellite system**	**Wireless**	**Wired**	**Cellular**
27	-	LAN 802.11g	Optic fiber 802.11u for access points	-
28	Portable satellite dish	RF as main links Ethernet switches at each hop 802.11 Wi-Fi to any unit in the area	Standard Ethernet for BS to access the backbone(camp)	-
29	-	ZigBee	-	-
30	-	RF	-	-

Power issues						
Deployment's ID	**Battery type**	**Battery capacity**	**Battery estimated lifetime**	**Battery replacement (if needed) frequency**	**Other forms of power supply**	**Power saving/management techniques**
27	X	24 Ah	NA	NA	Photovoltaic panel, particularly polycrystalline cells	Load regulator Idle/active modes
28	4 Large batteries of 12V for switches, access points and webcams 2 AA for sensor nodes	NA	NA	YES	Solar panels of 24V and 12V	Duty cycle of 6.67% Sleep for 14min and wake up for 1min Control beacons
29	EEMB LIR 17650 Li-ion rechargeable as secondary power source	1400mAh	NA	NA	BP SX305M Solar panel -2 Cooper Bussmann's super capacitors of 2.5V, 22F -AC-based ambient source (i.e. noise, vibrations) DC-based ambient source (i.i. solar radiation, thermal energy) These two forms of power are the primary power sources	MIC79110 battery charge controller Sleep mode
30	X	N/A	N/A	N/A	-	N/A

WSN cost/maintenance			
Deployment's ID	**Average price per node**	**Total cost/Estimated total cost**	**Maintenance tasks**
27	NA	NA	NA
28	NA	Not to exceed $20,000	NA
29	NA	NA	NA
30	N/A	N/A	N/A

Appendix E –Animal monitoring deployments

General information about deployment Livestock –Wildlife monitoring							
Deployment ID	Place of Deployment	Total project duration/chronology	Deployment area size/type	Monitoring subject	Measured factors	Topology/Architecture	Additional applications/observations
50	Dence woodland environment in Wythom Woods, Oxfordshire, UK	1 year in total	N/A	European budgers	-T -RH -Presence of the budgers	Peer to peer topology -RFID tags(collars) - RFID Detection nodes -Sensor nodes -Mobile sinks -Fixed GW	The deployment duration went through an evolution stages in HW as well as in SW to The cost of getting in the woods or animal tagging proved to be higher than the maintenance cost The suggestion that derives from this deployment is that, no initial deployment is perfect and that the best solution is to design a prototype, easily deployable
51	Farm with bulls in Australia	2 days (for 40min each day)	1ha paddocks	-	-Bull movements monitoring	Mesh network, multi hop topology Architecture: -Mobile actuator nodes -Laptop as BS	The Fleck platform, with the GPS on, consumes a maximum of 518mW power There has been developed a technique for autonomous bull separation, which is based on behavioral states of the animal The two days sessions were separated treatment session, where the sensor network was not activated and the control session, where it was activated During these sessions a camera recording was conducted for detailed analysis of bulls behavior

							Additional field test was implemented, this time on 13 cows Generally, this trial run successfully with the system performance at a high level for these 2 days and managed to increase the distance between the bulls
52	National Cattle Breeding Station at Belmont near Rockhampton of Queensland, Australia	6 months	N/A	-	-Soil moisture -Amount of food and water -Acceleration -Location -T -Battery voltage	Multi hop topology consisting of static, including relay nodes and mobile nodes A PC as BS	RFID ear tags also were used according to the Australian government The PC was running TOSBase application, a modified version of TinyOS Relay nodes act as gateway relaying data to the PC based BS The data from the BS was also sent to a remote PC and was stored in a DB The deployment described here provides a test bed for WSN research
53	Farm with cows in Australia	4 days from 3-7 May 2006	100x600m	-	-T	Multi hop	GPS data was recorded at 4Hz while the accelerometer and magnetometer data were recorded at 10Hz Ground truth observations were conducted on 2nd day of the experiment between 8am-11am including human observation of animal activities and video recording
54	Cattle farm in West Lothian, UK	2 days in summer 2006	N/A	-	-Location -WSN Health data	Multi hop	Simulations were implemented for system assessment
55	Fox house, Finland	One year starting April 11 2006	Large wooden building 15x17m	Foxes	-Luminosity -T & Humidity	Clustered, multi hop topology with front and rear cluster Including: -Sensor nodes (RFD devices) -Routing nodes (FFD) -Sink node -BS PC	One of the goals of this deployment was to study the reliability of wireless communication, thus two communication methods were used: 1st phase with the communication links being unidirectional with no acknowledgements while the 2nd phase included acknowledgements with three retransmissions The nodes were sleeping for 99.7% of the time All the data are stored in a MySQL DB PC's OS is Ubuntu Linux, Tomcat is used as HTTP server and the Web app is built on Apache Struts framework As for the reliability issue, the wireless links were

							very reliable, however the WSN could not guarantee for reliability because of node failures and the topology used
56	Kakadu National Park of Australia	N/A	1040 sq. m.	Cane toad, frog species	-Rainfall -T -Vocalization	Multi hop 3-tiered cluster network Which include: -Micronodes with constrained abilities -Macronodes micronodes with more abilities -BS	Both micronodes and macronodes will have acoustic sensors with the micronodes densely distributed, while macronodes are sparsely distributed because of their cost as for the BS's are less that macronodes The detection range of the micronodes is up to 20 meters and the spatial density for then is .001 nodes/sq m The PLEB is able to detect up to 22 frog vocalizations in the area
57	Mountain lions near Santa Cruz, CA, US (CARNIVORE)	15 days in fall 2008	N/A	Coyotes	-Location -Velocity -Activity and behavior of animal	Star topology Consisting of: -Static Relay Nodes (SRN) -Carnivore Sensor Nodes (CSN)	For tracking & recovery of the collars, time dropoff system, which at specified date and time causes the collar to fall off the animal, was implemented along with VHF beacons for locating the them at range of 0.1 to 20km There was conducted a test deployment of the network with three node and using a domestic dog and a human to carry out the CRN's, while a single SRN had a fixed placement Simulations were also implemented for 7 days with 16 collared coyotes and four randomly placed SRN's in an area of 64 sq km
58	Laboratory and a lawn as the test deployment areas, Northern Australia	N/A	100x100m outdoor area	Cane toad, frog species	-Frog vocalization	Grid topology , composed of hybrid network which includes resource poor and rich sensor nodes	The lab test of the WSN was implemented by playing playbacks of nine individual frog species calls and seven different mixtures of these frog vocalizations as sound sources The Stargate uses a Logitech USB Desktop Microphone, corresponding to 100-16kHz while the Mica2 used the standard mic The WSN in both indoor and outdoor tests had a really good performance, of course in the indoor test performed better for obvious reasons The authors propose the hybrid model that is, comprised of different platforms, is more suitable for this type of monitoring
59	Great Duck Island off the coast of	4 weeks summer of 2002	N/A	Leach's Storm Petrel, a	-T -Light intensity	Tree based, multi hop topology	Use of PDA-sized devices for direct communication with the sensor patch

	Maine			seabird colony	-Barometric pressure –RH -Occupancy Weather board: -T -H -Barometric pressure - Light -Occupancy	Multi-tiered architecture: -Sensor patches - Gateways - Local transit network - BS	Single hop mote to mote communication for GW Postgres SQL DB for data storing Each node periodically sent to the GW health and status messages
60	Great Duck Island off the coast of Maine	4 months summer 2002	N/A	Leach's Storm Petrel	-H -Pressure -T -Ambient light -Presence of a Petrel	Multi-level structure: -1st: sensor patch -2nd: gateway - 3rd: BS - 4th: Remote servers Single hop network for motes	High node failure rates due to collisions The sensors also had problems, although the most reliable was the light sensor The T sensor was effected by direct sunlight which enter the enclosure as a result to heat up the mote Generally the sensors were affected by the environmental conditions, proving the enclosure as inadequate 5 of 43 nodes have exhausted their original battery supply
61	Great Duck Island off the coast of Maine	4 months during summer and autumn 2003	N/A	Leach's Storm Petrel	**Burrow motes:** -Ambient T -H -Occupancy of nesting **Weather motes:** -T & H -Barometric pressure	Tree topology, in tiered architecture consisting of sensor motes, gateways, BS	Cameras were installed inside the burrows to correlate with the infrared sensor readings and true occupancy by collecting 15sec video every 15min The 1st single hop network deployment started on June 8th and after one week on June 16th, the 2nd multi hop network was deployed The backend infrastructure such as the transit network, base stations and relational DBs were deployed before the motes Because of the addition of nodes, the packet loss rate was relatively high and the network wasn't function properly as a total
62	Sweetwaters game reserve, Central Kenya	Since January 12th 2004	100 sq km	Zebras	-Position	Mobile, single hop topology comprising of - mobile nodes (collars) - mobile BS	The mobile BS is a manned vehicle, which periodically come in contact with a zebra to download the data The accuracy of the GPS, which is the primary sensing device, is determined by two characteristics: -The number of satellites being in view of the GPS antenna -The configuration of the satellites visible to the

							GPS antenna The collars worn by zebras were affected their behavior within a week Due to long distances between collars and the issue of radio absorbance from the animal's body, the signal weakened, so this issue solved by using foam dielectric material
63	Cloud forest of North-Western slopes of the Ecuadorian Andes (pilot project)	March 29-April 3 2010	The area is between 1200-2800m a.s.l. with tropical climate and rich flora and fauna	Wild species	-Light	Stationary and mobile nodes	Preliminary test were conducted with these stationary and mobile nodes by the scientists in the jungle to determine the communication range under heavy rain and high humidity RSSI and LQI were checked for the system evaluation These experiments run without presence of WSN expertise, with limited equipment and in isolation Due to absence of computer, the scientists used the nodes LED's to visualize their functionality
64	Rumbula airfield and Sampeteris forest, Latvia (LynxNet pilot)	N/A	N/A	Eurasian Lynx	-Location -T -RH -Ambient light -Motion vector	Single hop topology including collars, BSs and client devices	For testing the radios, CC240 was used for comparison with TRM radio, already used here and which provide long range coverage Instead of Lynxes, a dog was used to perform system evaluation, because it was easier than with lynxes According to the results, the achievable radio communication range can be up to 200-250m
65	Wildlife passages in the Donana National Park, South-Western Spain	N/A	2.5ha	Wild animals behavior in relation to the passages	-Animal presence -Identification	Single hop topology in hexagonal layout network consisting of: -detector nodes -camera nodes -PC based BS	Both detection and camera nodes include PIR sensors All the data gathered from the detection and camera nodes are stored in the master camera node, which is equipped with a storage device and sometime latter this data is downloaded from a PC operator located in the Park, thus real time data is not required The CMOC image sensor has a resolution of 640x480 and an angle of view 90^{o} The criteria of accepting a target detection is to be detected by 2 or more different nodes Prior to real deployment, simulations were conducted

WSN Hardware											
Deployment's ID	Node platform	Microcontroller	Radio transceiver	GPS	Radio antenna	Memory type/ size of a node	Sensor	No of nodes/collars	Installation issues	Collar tag attachment technique	Waterproof case
50	TmoteSky	MSP430	N/A	NO	N/A	Flash: 48KB RAM:10kbyte	-Sensirion SHT71 for T & RH	10 sensor nodes, 26 detection nodes and 74 RFID tags	One of T sensors was buried 30cm underground, while the RH sensor was mounted at 1m height 10 of sensor nodes were deployed in the woods for microclimate measurement while the RFID collars were tagged on monitored animals The 26 detection nodes were placed at setts and latrines	During 9 routine trapping sessions	YES
	Zigbit Amp	AVR Atmega 1281V	N/A			RAM:8kbyte Flash:128kbyte					
51	Fleck	Atmega 128	Nordic903 at 433MHz	YES	½ wavelength of 20cm whip RF Yagi attached to the laptop GPS antenna	On-board flash:8MB	-Probes for stimuli application	5	-	Bulls were held in a standard cattle crush while a professional fitted the equipment	IP55 plastic boxes

52	Fleck 1 and 2	Atmel Atmega 128	Nordic903 at 433MHz	YES	High gain omnidirectional antenna at the roof for High gain Yagi	On-board flash MMC flash card	-3-axes accelerometer -Electronic 3-axis compass - GPS receiver	60 sensor nodes from which 40 are mobile	The soil moisture nodes are buried at different depths underground varying from 0.01-1m The mobile nodes are worn by the cattle	N/A	N/A
53	Fleck 2	N/A	N/A	YES	RF antenna	On-board flash	-Accelerometers -Magnetometers	6 collars	Worn on the cows	N/A	N/A
54	Micaz	N/A	N/A	YES	N/A	128KB RAM:4KB	N/A	14 collar nodes + BS	-	-	N/A

55	CiNet + sensor board with photodiodes	ATmega 128L 8-bit	Chipcon 2420 at 2.4GHz	NO	External for routing nodes and on-chip for sensor nodes	Flash:128K SRAM:4K EEPROM4K	DS1621 sensor for T	14 of which 10 are sensor nodes, 3 are routing node and 1 sink node	The sensor nodes are organized in two clusters where the rear cluster consists of 3 nodes while the front one of 6 nodes One battery powered node was installed near BS	-	YES
56	PLEB	Intel 486 CPU at 25MHz	N/A	YES	N/A	N/A	-Acoustic sensors	16	The area of the Park is divided into 2000 regions of 10 sq.km. each, because it considered small enough to experiment and learn, following this these zones are categorized into 3 types of zones, based on which areas are most likely to host these frogs	-	N/A
57	Carnivore platform	MSP430	CC2420	YES	A folded-F printed circuit board(PCB) 12dBi high directional	MicroSD card: 2GB	-Lassen GPS iQ receiver for location & velocity -MMA7260Q accelerometer for activity & behavior	3 collars + portable SRN	The collars were worn by coyotes	N/A	YES

58	Mica2 with MTS300 sensor board and Stargate platforms	Atmega at 7.7MHz for Mica2 Intel PXA255 at 400MHz for Stargate	N/A	-	N/A	On-board flash for Mica2 and RAM: 4kbyte Flash: 32MB and SDRAM: 64MB for Stargate	Acoustic sensors	50	Randomly deployed in the area	-	-
59	Mica + Mica weather board	Atmel Atmega 103 at 4MHz	Single channel 916MHz radio from RF Monolithics for bidirectional communication	NO	14dBi directional 916MHz Yagi	Nonvolatile: 512KB	N/A	32 of which 9 are placed inside the burrows	Inside and outside of burrows when the island was empty of the seabirds	-	Acrylic enclosure
60	Mica	N/A	N/A	NO	Board-mounted miniature whip antennas for motes	N/A	-Photoresistor for light intensity	43	Inside and outside of burrows when the island was empty of the seabirds	-	Acrylic enclosure
61	Mica2Dot	Atmel ATmega 128 at 4MHz	Chipcon at 433MHz for 1st network 435MHz for 2nd one to avoid interferences	NO	N/A	Flash: 512KB	Burrow sensors: -Melexis MLX90601 and Sensirion SHT11 for ambient and air T & H Weather sensors: -Sensirion SHT11 for T & H -Intersema MS5534A barometer	98 sensor nodes, from which 62 burrow and 36 weather nodes, were deployed in 2 sensor	The 1st network is a single hop where the GW was at the western edge and nodes here performed only sampling forming ellipse of 57m The 2nd network was multi hop and the total length was 221m with a width of 71m	-	YES

							-2 TAOS TSL2550 light sensors -2 Hamamatsu S1087 photodiodes	networks			
62	N/A	TI MSP430F149 16-bit RISC	MaxStream 9XStream at 900MHz	μ-blox GPS-MS1E chip	Dipole GPS antenna	Flash: 60kB RAM: 2kB Flash: 4Mbit	GPS sensor unit	7 collars	The collars were installed in 6 female zebras and 1 male	N/A	YES
63	TmoteSky	N/A	Chipcon CC2420 at 2.4 GHz	NO	On-board inverted-F-micro-strip omnidirectional	External flash	-	18 nodes	Stationary motes were attached to trees in cross configuration while the mobile ones were carried from the biologists, which made use of the system	-	IP65
64	Tmote Mini	TI MSP430F1611	LINX TRM 433LT at 433MHz	YES	Four stacked half-wave dipole collinear antennas for BS	N/A	-3D accelerometer and 2D gyroscope for motion vector calculation	One collar + one BS	The collar worn by the animal while the BS placed in fixed location	-	YES
65	Imote2 + RTS400CA sensor board + IBM400 multimedia Sensor board	Marvell PXA271 XScale at 13-416MHz (main) MMX DSP as coprocessor	TI CC2420 at 2.4GHz	NO	N/A	SRAM: 256MB FLASH: 32MB SDRAM: 32MB	-PIR (Passive Infrared)motion sensors for target detection by Panasonic AMN41121 -OV7670 CMOC image sensor	20 detection nodes 3 camera nods	The detection nodes were densely deployed in the monitored area 1m above the ground. The Master camera was placed on top of the entrance, a second camera was places on the edge of the road, 40m away from the passage and the last one was installed	-	IP67

									symmetrically in the opposite site of the formed semicircle		

Deployment ID	Sensor node's sensing/sending data packets				Data transmission/communication	
	Time-based	Sampling rate (Hz)	Event-driven	Requirement-based	Single-hop	Multi-hop
50	T & RH data measurements every 5min	N/A	-	-	-	X
51	X	N/A	-	-	X	-
52	X	N/A	-	-	-	X
53	X	N/A	-	-	-	X
54	X	N/A	-	-	-	X
55	Every 5min	N/A	-	-	-	X
56	At nights	N/A	-	-	-	X
57	X	60 Hz for accelerometer	-	-	X	-
58	X	22kHz for Stargate	-	-	-	X
59	Almost every sec for burrow sensors	Different for every sensor	-	-	X	X
60	Every 70s	-	-	-	Between sensor nodes	-
61	Every 5min for single hop motes Every 20min for multi hop motes	-	-	-	1st network	2nd network
62	Every 8min	-	-	-	In pairwise connections	-
63	X	-	-	-	X	-
64	The packet with GPS positions and other sensing data was formed every hour The packet with the accelerometer and gyroscope	-	-	-	X	-

	data every 5min					
65	Periodical fixed sampling	Depends on the target speed	-	-	X	-

WSN's Software			
Deployment ID	Protocols	Algorithms	Node OS
50	X-MAC IPv6 UDP 802.15 Data protocol(L-series) TCP/IP uIP IPv6 networking stack protocol	Delta-based compression Routing algorithm Duty cycling algorithm Data collection algorithm	ContikiOS
51	ZigBee protocol MAC	State machine-based algorithm	TinyOS
52	N/A	N/A	Modified TinyOS
53	Deluge	N/A	N/A
54	Implicit Routing Protocol (IRP) Flooding & communication protocols	N/A	TinyOS
55	802.15.4	N/A	N/A
56	N/A	Compression algorithm	N/A
57	ZigBee protocol stack MAC 802.11 CSMA/CA Carnivor network protocol Neighbor discovery protocol	FIFO algorithm	N/A

58	N/A	Fourier Transform algorithm Scheduling algorithm GCPF Thresholding algorithm Noise reduction algorithm Compression algorithm	N/A
59	MAC Access protocols	N/A	TinyOS
60	MAC Access protocols	N/A	TinyOS
61	802.11b IP Ethernet	N/A	TinyOS
62	Flooding protocol Communication protocol	N/A	Impala OS
63	N/A	N/A	TinyOS
64	MAC CSMA	Encoding/decoding algorithm based on Manchester encoding (ME)	MansOS
65	802.15.4 CSMA/CA	JPEG compression algorithm	TinyOS

Network issues				
Deployment ID	Satellite system	Wireless	Wired	Cellular
50	-	RF between RFIDs and detection nodes 802.11 link from sensor node to sensor node and from sensor node to detection nodes and to mobile sinks	-	3G for fixed GW
51	-	802.15.4	-	-
52	-	High gain radio link for static nodes to connect to Internet	-	-
53	-	RF	-	-
54	-	RF	-	-
55	-	802.15.4 between sensor and routing nodes	RS232 connection between sink node and the PC	-
56	-	RF	-	-
57	-	802.15.4 between CSN's and CSN's to SRN's + Wi-Fi or long range ZigBee between SRN's	-	-
58	-	802.11b for Stargate RF between Mica2and Stargate nodes	-	-
59	Two-way satellite connection with the satellite connected to a laptop from which the users can access the WSN	WLAN between sensor nodes and BS	WAN between BS and end users	-
60	Satellite connection	-	-	-
61	DirecWay 2-way satellite system providing WAN connectivity	RF between motes	WAN for the BS and other equipment in the study area	-
62	-	RF between collars and BS	-	-
63	-	RF	-	-
64	For GPS data transmission	RF between collars and BS And between BS and end users	USB between BS and end users	-
65	-	IEEE 802.15.4 between detection nodes and the Master camera node	-	-

Power issues						
Deployment ID	Battery type	Battery capacity	Replacement frequency(if needed)	Battery estimated lifetime	Other forms of power supply	Power saving/ management techniques
50	CR2450 coin cell 3V battery for RFIDs SLA for readers	N/A 18Ah	N/A	2years	Solar panel for fixed GW Charge pump for nodes	Duty cycling for RFID tags
51	2 NiMH rechargeable	N/A	-	N/A	-	-
52	3 NiMH rechargeable for relay nodes 2 rechargeable	2500mAh 2500mAh	N/A	N/A	Solar panels	N/A
53	X	N/A	N/A	N/A	N/A	N/A
54	2AA	N/A	N/A	N/A	-	N/A
55	Battery for the external sensor node	N/A	-	N/A	Electricity	Duty cycling for sensor nodes
56	N/A	N/A	N/A	N/A	N/A	Sleeping periods mostly at day
57	D-cell Li	N/A	N/A	N/A	-	Dual MOSFET's for power control Sleep wake up mode for individual modules
58	2AA for Mica2 Li-ion for Stargate	N/A	N/A	N/A	-	N/A
59	2AA	2 Ah	N/A	N/A	Solar power for GW	DC booster Sleep wake mode
60	Rechargeable for GW 2AA for motes	N/A	YES	N/A	Solar cell for GW	N/A

61	3.6V Electroshem SB880 for burrow motes 2.8V SAFT LO34SX	N/A	N/A	N/A	Photovoltaic system for BS, satellite link and supporting equipment	Low power listening which woke up periodically the motes to conduct their activities and then go back to sleep
62	Li-ion rechargeable	N/A	-	N/A	Solar array of 14 solar modules each Linear regulators for MCU and GPS antenna power Switch converters for GPS and radio power	Duty cycling of sensors and GPS
63	2 size D for stationary nodes 2AA for mobile ones	N/A	N/A	N/A	-	N/A
64	3.7V Li-Poly	1100mAh	N/A	1.5 months	-	Duty cycle
65	3AA NiMH rechargeable cell units	3200mAh	N/A	N/A	-	Duty cycling Sleep wake up mode

WSN cost/maintenance/risk assessment				
Deployment ID	Average price per node	Maintenance cost (in terms of labor and money)	Total cost/Estimated total cost	Damage possibility
50	N/A	High cost for battery replacement once every 4 months	$12.240 (including the 74 RFID tags and the 26 detection nodes)	Low
51	N/A	N/A	N/A	High
52	N/A	N/A	N/A	Medium
53	N/A	N/A	N/A	Medium
54	About 1700Euro	N/A	N/A	Medium

55	N/A	N/A	N/A	Low
56	About 800Euro (1000 AUD) a PLEB	N/A	N/A	No
57	Under $1000 per collar	N/A	N/A	High
58	N/A	N/A	N/A	NO
59	N/A	N/A	N/A	Low
60	N/A	Battery replacement	N/A	Low
61	N/A	N/A	N/A	Low
62	N/A	N/A	N/A	Low
63	N/A	N/A	N/A	NO
64	N/A	N/A	N/A	High
65	N/A	N/A	N/A	Medium