Wireless Sensor Networks: A Survey on Environmental Monitoring

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Wireless Sensor Networks: a Survey on Environmental Monitoring

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***Abstract*— Traditionally, environmental monitoring is achieved by a small number of expensive and high precision sensing unities. Collected data are retrieved directly from the equipment at the end of the experiment and after the unit is recovered. The implementation of a wireless sensor network provides an alternative solution by deploying a larger number of disposable sensor nodes. Nodes are equipped with sensors with less precision, however, the network as a whole provides better spatial resolution of the area and the users can have access to the data immediately. This paper surveys a comprehensive review of the available solutions to support wireless sensor network environmental monitoring applications.**

***Index Terms*— Wireless Sensor Networks; Low-Power Personal Area Networks; Mesh Networks; IEEE 802.15.4; Environment Monitoring.**

I. INTRODUCTION

Environmental monitoring has a long history. In early times analog mechanisms were used to measure physical environmental parameters. Some of them with the ability to record the values on paper dish. The old mechanisms recorded data at specific intervals and required human intervention to download them.

Some years ago, digital data loggers have replaced the old mechanical. The digital data loggers are more easy to operate and to maintain and more cheaper than the old mechanisms. Digital data loggers may also be combined with long-range communication networks, such as GSM, to retrieve data from remote sites. However, digital data loggers have some drawbacks. The digital data loggers solution, usually provide monitoring at one point only and in many cases multiple points need to be monitored. There is not a standard to store data and to communicate with the data logger, so several different solutions are used.

Recent advances in micro-electro-mechanical systems and in low-power wireless network technology have created the technical conditions to build multi-functional tiny sensor devices, which can be used to observe and to react according to physical phenomena of their surrounding environment [1]. Wireless sensor nodes are low-power devices equipped with processor, storage, a power supply, a transceiver, one or more sensors and, in some cases, with an actuator. Several types of sensors can be attached to wireless sensor nodes, such as chemical, optical, thermal and biological. These wireless sensor devices are small and they are cheaper than the regular sensor devices.

The wireless sensor devices can automatically organize themselves to form an ad-hoc multi hop network. Wireless sensor networks (WSNs), may be comprised by hundreds or maybe thousands of ad-hoc sensor node devices, working together to accomplish a common task. Self-organizing, self-optimizing and fault-tolerant are the main characteristics of this type of network [2]. Widespread networks of inexpensive wireless sensor devices offer a substantial opportunity to monitor more accurately the surrounding physical phenomena's when compared to traditional sensing methods [3]. Wireless sensor network has it own design and resource constrains [4]. Design constrains are related with the purpose and the characteristics of the installation environment. The environment determines the size of the network, the deployment method and the network topology. Resources constrains are imposed by the limited amount of energy, small communication range, low throughput and reduced storage and computing resources. Research efforts have been done to address the above constrains by introducing new design methodologies and creating or improve existing protocols and applications [1,2].

This paper provides a review on wireless sensor networks solutions to environmental monitoring applications. The remainder of this paper is organized as follows. Section II gives an overview of sensor network platforms. Section III analyses the standard IEEE 802.15.4 [5] while Section IV overviews recent sensor architectures. WSN environmental monitoring projects are presented in Section V and challenges related with environment sensor networks are studied in Section VI. Section VI concludes the paper and addresses future research challenges related to WSN networks deployment.

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II. SENSOR NETWORK PLATFORMS

Sensor nodes are the elementary components of any WSN and they provide the following basic functionalities [1-2,7]: *i*) signal conditioning and data acquisition for different sensors; *ii*) temporary storage of the acquired data; *iii*) data processing; *iv*) analysis of the processed data for diagnosis and, potentially, alert generation; *v*) self-monitoring (e.g., supply voltage); *vi*) scheduling and execution of the measurement tasks; *vii*) management of the sensor node configuration; *viii*) reception, transmission, and forwarding of data packets; and *ix*) coordination and management of communications and networking.

To provide the above-described functionalities, as illustrated in Figure 1, a sensor node is composed by one or more sensors, a signal conditioning unit, an analog-to-digital conversion module (ADC), a central processing unit (CPU), memory, a radio transceiver and an energy power supply unit. Depending on the deployment environment, it can be necessary to protect the sensor hardware against mechanical and chemical aggressions with an appropriate package.

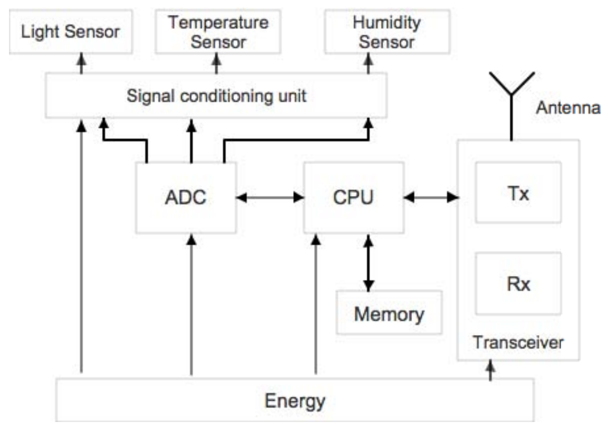

Figure 1 - Sensor node hardware architecture.

Sensor node hardware devices can be classified into three different main categories [8]:

• Adapted general-purposes computers. This sensor platform uses hardware similar to embedded personal computers hardware, personal assistants devices and low-power personal computer devices. Windows and Linux are the mainly used operating systems. High level programming languages can be used to develop software components. Usually supports simultaneous layer two low power protocols and layer two local area protocols. Processing capabilities, multiple layer two protocol support and versatility are the main advantages of this hardware platform. However, they consume a considerable amount of energy when compared with other hardware platforms. Adapted general-purposes computer platform are usually used as a gateway to connect the wireless sensor network to other networks.

• Embedded sensor modules. This sensor hardware platform uses commercial off-the-shelf (COTS) chips. These platforms are cheaper than the previous because COTS chips are produced in large scale. A microcontroller unit (MCU) is used as central processing unit. The C programming language is usually used to program the platform, enabling the development of thigh code that fits in their limited memory size.

• System on chip. This platform uses application specific integrated circuits (ASIC), which integrate all sensor hardware components. Because of this integration, systems on chip platforms are extreme low power, cheap and small size.

Hardware management, scheduling policies, multi-threading and multitasking are some of the low level services to be provided by an operating system (OS). Moreover, the operating system should also provide the support for dynamic loading and unloading of modules, provide proper concurrency mechanisms, Application Programming Interface (API) to access underlying hardware and enforce proper power management policies. The achievement of those services in WSN is a non-trivial problem, due to the hardware constrains [9]. A classification framework that compares the existing operating systems according to the core OS is proposed on [9]. The core OS features that constitute classification framework are architecture, reprogramming, execution model and scheduling. Other features such as power management, simulation support, and portability also has been considered. The proposed framework was used to compare and evaluate the existing operating systems. The operating systems were also evaluated according to WSN application. TinyOS [10] and Contiki [11] are the most used operating systems.

Several energy storage devices are available. Battery is the most common energy storage device. Fuel cells and ultracapacitors are presented as promising technologies. Energy harvesting techniques can be used to increase the sensor energy autonomy [12]. Energy harvesting schemes developed in the laboratory have generated 10 μW of power from mechanical vibrations [13]. This energy is enough for low-frequency digital signal processor. Advances in energy harvesting and improvements in node integration will make possible to produce a battery less infinite-lifetime sensor device. Wireless data transmission consumes more energy than data processing. So it is preferable to process the data at the sensor in order to minimize the data transmitted to the other nodes. The power consumed when the radio is in receive mode is almost equal to that consumed when it is transmitting [7]. So, the radio must be turned off when it is not required. Moreover, sensor nodes must take advantage of long periods of idle time between interesting events to save energy. In the inactivity periods, the sensor cans gracefully scaling back their energy consumption. So, it is crucial defining the network's performance requirements using metrics ranging from latency to accuracy and reliability. Then, the network performs just enough data computation, and data receptions and transmissions to meet the WSN application requirements. Turning off the sensor poses the problem of how neighboring nodes can be organize to wakeup at the same time to communicate. Several approaches were proposed to address this problem, such as [14] and [15].

III. IEEE 802.15.4 OVERVIEW

The standard IEEE 802.15.4 [5] released in 2003, represented a millstone because it was the first low-power layer two standard for low power wireless personal area network (LoWPAN). Several technologies have been specified using IEEE 802.15.4 as link layer technology, some of them proprietary, such as ZigBee [16] and WirelessHART [17]. The ZigBee was created by ZigBee alliance and defines the network, security and application layers. The ZigBee alliance also publishes application profiles that allow multiple vendors to create interoperate products. The WirelessHART is an open-standard wireless networking technology proposed by HART Communication Foundation and it is also based in IEEE 802.15.4. It is mainly used in industrial environments. WirelessHART, like ZigBee, is a stand-alone standard; consequently do not support communications with other networks without using a specific gateway device.

IEEE 802.15.4 physical layer provides an interface between the medium access control (MAC) sub-layer and the physical radio channel. Two services are provided, the physical data service and the physical management service. The physical layer is responsible for the following tasks: i) activation and deactivation of the radio transceiver, ii) energy detection (ED) sensed on the current channel, iii) clear channel assessment (CCA) for CSMA/CA, iv) channel frequency selection, v) link quality indication (LQI) for received packets and vi) data transmission and reception.

The physical layer is responsible to turn the radio transceiver into one of the three states, that is, transmitting, receiving, or sleeping (equivalent to turn off the radio transceiver) according to the information returned by MAC sub-layer.

Energy detection (ED) sensed on the current channel is executed by physical layer and is an estimate of the received signal power of an IEEE 802.15.4 channel. No attempt is made to identify or decode signals on the channel in this procedure. The result from energy detection can be used as part of a channel selection algorithm or for the purpose of clear channel assessment (CCA).

The physical layer performs CCA using energy detection, carrier sense or a combination of both. In energy detection mode, the medium is considered busy if any energy above a predefined energy threshold is detected. In carrier sense mode, the medium is considered busy if a signal compatible with IEEE 802.15.4 is detected. In the combined mode, both conditions above-mentioned must occur in order to conclude that the medium is busy.

Wireless links under IEEE 802.15.4 can operate in 27 different channels. So, the physical layer should be able to adjust its transceiver into a certain channel according with the information received from the MAC sub-layer.

Link quality indication (LQI) measurement is performed by the physical layer for each received packet. The physical layer uses energy detection function, a signal-to-noise ratio or a combination of these to measure the strength and/or quality of a link from which a packet is received.

Modulation and spreading techniques are used to transmit the data over radio channel. Data reception is also a physical layer function.

The IEEE 802.15.4 defines the following three physical operation modes: 20 kbps at 868 MHz, 40 kbps at 915 MHz, and 250 kbps at 2.4 GHz (DSSS).

A device in an IEEE 802.15.4 network can use either a 64-bit address or a 16-bit short IEEE address assigned during the association procedure. An 802.15.4 network can accommodate up to 64k (2^{16}) devices.

The frame length is limited to 127 bytes because low-power wireless links are used in communications and the sensors have limited buffering capabilities.

The IEEE 802.15.4 define the following two types of devices; full-function devices (FFD) and reduced-function devices (RFD). In FFD all network functionalities are implemented and therefore can be used in peer-to-peer topologies and multi-hop communications are supported. Reduced-function devices only support a limited set of functionalities and they are used to measure physical parameters and to execute uncomplicated tasks. An RDF device does not support multi-hop communications.

FFD and RFD devices organize themselves in personal area network (PAN). A PAN is controlled by a PAN coordinator, which has the function of setting up and maintaining the network. Only FFD devices can assume the role of PAN coordinator.

The MAC sub-layer provides an interface between the service specific convergence sub-layer and the physical layer. Like the physical layer, the MAC sub-layer also provides two services, namely, the MAC data service and the MAC management service. The MAC sub-layer is responsible for the following tasks: i) support PAN node association and disassociation, ii) transmit network beacons if the device is a PAN coordinator; iii) synchronize to the beacons, iv) use carrier sense multiple access with collision avoidance (CSMA/CA) mechanism for channel access, v) support the guaranteed time slot (GTS) mechanism and vi) provide a reliable link between two peer MAC entities.

To support self-configuration, IEEE 802.15.4 embeds association and disassociation functions in its MAC sub-layer. This not only enables a star to be setup automatically, but also allows the creation of self-configuring peer-to-peer network topologies.

A coordinator must determine if the beacon-enabled mode is required, in which a superframe structure is used. In the beacon-enabled mode, a coordinator sends out beacons periodically to synchronize the other PAN nodes. A device attached to a coordinator operating in a beacon-enabled mode must track the beacons to be synchronized with their PAN coordinator. This synchronization is important for data polling and for energy saving purposes.

The IEEE 802.15.4 MAC provides two modes of operation, the asynchronous beaconless and the synchronous beacon enabled mode. The beaconless mode requires nodes to listen for other nodes transmission all the time and as a consequence drains the battery power fast. The beacon-enabled mode is designed to support the transmission of beacon packets between transmitter and receiver providing synchronization among nodes. In the beacon-enabled mode, the PAN coordinator broadcasts a periodic beacon containing information about the PAN. Synchronization provided by the beacons allows devices to sleep between transmissions, which result in energy efficiency and extended battery lifetime. Supporting beacon-enabled mode in peer-to-peer topologies is currently considered a challenge.

The period between two consecutives beacons defines a superframe structure that is divided in to 16 slots. Beacon always occupies the first slot, while the others is used to data communication. In order to support low-latency applications, the PAN coordinator can reserve one or more slots, designated by guaranteed time slots, which are assigned to devices running such applications. These devices do not need to use contention mechanisms before transmit. The beaconless mode doesn’t permit superframe structures, so guaranteed time slots cannot be reserved. As a consequence, only random access methods, such as unslotted CSMA/CA can be used to medium access. The IEEE 802.15.4 CSMA/CA does not include the request-to-send (RTS) and clear-to-send (CTS) mechanism, because low data rate is used.

The MAC sublayer employs various mechanisms to enhance the reliability of the link between two peers, among them there are the frame acknowledgment and retransmission, data verification by using a 16-bit CRC, as well as CSMA/CA.

A PAN can adopt one of the following two network topologies [18]: star topology and peer-to-peer topology.

In a star topology a master-slave network model is used (Figure 2). An FFD device assumes the PAN coordinator role and controls all the networks operations. Other nodes can be RFDs or FFD and communicates only with PAN coordinator. This topology is better suited for small networks. In this configuration the PAN coordinator

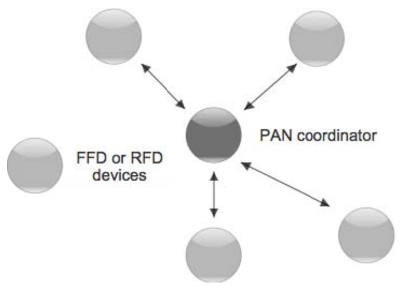

Figure 2 – Illustration of a star topology.

In peer-to-peer topology FFD devices can communicate with other FFDs within its radio range and can use multi-hop communications to send messages to other FFDs outside of its radio range. RFDs can communicate only with FFDs (Figure 3).

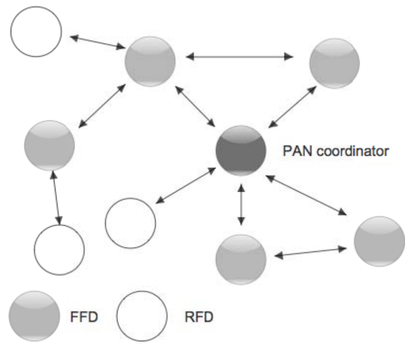

Figure 3 - Illustration of a peer-to-peer topology.

Peer-to-peer topology supports more complex topologies, such as mesh or hierarchical cluster. A mesh network topology is a PAN that uses one of two connection configurations: full mesh topology or partial mesh topology. In the full mesh topology, each node is connected directly to each of the others. In the partial mesh topology, some nodes are connected to all the others, but some of the nodes are connected only to limited number of nodes. When compared to star topologies, mesh networks have the capability to provide extension of network coverage without increasing transmit power or receive sensitivity, better reliability via route redundancy, easier network configuration and better device battery life, due to fewer retransmissions. As IEEE 802.15.4 does not define any path selection mechanism, the IEEE 802.15.5 [6], also known as mesh WPAN, was chartered in November 2003 to develop the necessary mechanisms that must be present in physical and medium access control layers of WPANs to enable mesh networking. The work of the IEEE 802.15.5 group covers both high-rate and low-rate WPANs. So, the outcome of this work group is applicable on IEEE 802.15.3 (high rate PAN) and on IEEE 802.15.4 protocols.

Many routing protocols have been specifically designed for WSNs [19] where energy awareness is an essential design issue. Routing protocols in WSN can be classified from the perspective of network structure in three different classes, flat based, hierarchical based and location based. In flat based routing, all network devices have the same roles in the routing topology. In hierarchical based routing, nodes can play different roles. Nodes with higher resources can be used in multi-hop forwarding and the other nodes can be uses in sensing functions. In location based routing, sensors are addressed according to their location, and data are routed using node positions. The routing mechanisms must take in consideration the network purpose and the architecture requirements.

IV. Overview of Recent Sensor Architectures

Reduced instruction set computer (RISC) microcontrollers with a small program and data memory size are used on low-end and low-cost sensors devices.

Additionally, an external flash memory can be used to provide secondary storage. Two approaches have been adopted for the design of sensing equipment [7]. The first approach uses a sensing board that can be attached to the main microcontroller board through an expansion bus. Usually, more than one can be attached. This is the most expandable approach and can be found on Iris platform [20]. A typical crossbow sensing board provides light, temperature, microphone and two-axis accelerometer device. Other boards only have I/O connectors and can be used to connect custom sensor to the main board. In the second approach, the main board also includes the sensing devices. The sensing devices are soldered or can be mounted if needed. The expandability is affected because the available sensing devices options are very limited. The second approach can be used to reduce the production costs. TelosB [21] vendor follow the second approach.

Currently, the most popular sensors platforms employ one of two type radios designed by Chipcon [22], the CC1000 and the CC2420. The CC1000 is the simpler and the cheaper alternative. It offers a basic medium access control protocol, operates in a license free band (315/433/868/915 MHz) and has a bandwidth in the range 20-50 Kbps. It has a simple byte oriented interface that allows software implementation of other MAC protocols. The CC2420 is compliant with IEEE 802.15.4 specification, operate at 2.4 GHz license free band and has 250Kbps bandwidth.

There are two popular microcontrollers used on WSN platforms, the ATMega 128L [23] and Texas Instruments MSP430 [24]. The ATMega 128L has 128KB of code memory and 4KB of data storage. The MSP430 has 48KB of code memory and 10KB for data storage.

An exhaustive list of sensor boards, vendors and their main characteristics are presented in [25].

Currently available sensor platforms mainly use two size AA battery cells. Standard batteries are cheaper and easy to replace. However they limit the platform size reduction.

TinyOS and Contiki are the most used open source and freeware WSN operating systems [9]. TinyOS is an event driven operating systemand it uses a C-like programming language (NesC), although incompatible with C standard, which has a very low memory footprint. Commands and event handlers may post a task, which is executed by the TinyOS first-in first-out (FIFO) scheduler. These tasks are non preemptive and run to completion. TinyOS supports power management functions. TinyOS is gaining its importance in the WSN applications and has been ported to different platforms. Although popular, TinyOS has some drawbacks, namely the lack of supporting fault tolerance, preemptive multitask, priority scheduling, dynamic programming, and real time grantees. Contiki OS merges the advantages of both events and threads execution models. It is primarily an event driven model but it also supports optionally preemptive multi-threading as an optional application level library. Events in Contiki OS are classified as synchronous and asynchronous. Synchronous events are scheduled immediately and asynchronous events are scheduled afterward. In Contiki, everything such as communications, device drivers and sensors data handling are supported as a service and each service has an interface and implementation. Contiki OS also has support for dynamic loading and replacement of individual programs and services in runtime. Applications are developed using C++ standard language. There are simulation tools to both operating systems. TOSSIM [26] simulates TinyOS applications for sensor network and Cooja [27] is a simulation environment for Contiki OS. Both operating systems have support for IPv4 and IPv6 protocols.

V. WSN ENVIRONMENTAL MONITORING

Environment monitoring is a natural candidate for applying wireless sensor networks, since the physical variables that must to be monitored, e.g., temperature. They are usually distributed over large regions.

Environmental monitoring applications can be broadly categorized into indoor and outdoor monitoring [28]. Indoor monitoring applications typically include buildings and offices monitoring. These applications involve sensing temperature, light, humidity, and air quality. Other important indoor applications may include fire and civil structures deformations detection. Outdoor monitoring applications include chemical hazardous detection, habitat monitoring, traffic monitoring, earthquake detection, volcano eruption, flooding detection and weather forecasting. Sensor nodes also have found their applicability in agriculture. Soil moisture and temperature monitoring is one of the most important application of WSNs in agriculture. Only outdoor environmental monitoring will be considered in this work.

When monitoring the environment, it is not sufficient to have only technological knowledge about WSN and their protocols. It is also necessary the knowledge about the ecosystem.

Several projects, with real implementations, had focused on environmental sensor networks; some of them are presented bellow.

GreatDuckIsland [29] was the first WSN implemented for habitat monitoring purposes. College of Atlantic and Berkeley University conducts field research on several remote islands. One of them, Great Duck Island (GDI) is located 15Km south of Mount Desert Island, Main. Studying the usage pattern of the nesting burrows when one or both parents alternate between incubation and feeding is the major objective of this project. A single hop hierarchical network comprises 32 nodes in the first phase and 120 in the last were set up at GDI. Berkeley Mica sensor nodes with TinyOS installed were used to measure temperature, humidity and atmosphere pressure and to detect the presence of the birds. Readings from sensor nodes are periodically sampled and relayed from the local sink node to base station on the island. The base station sends the data using a satellite link to a server connected to the Internet.

Sonoma Dust [30] is a WSN, constituted by 120 Mica2dot nodes that were installed on Sonoma County, California to monitor the redwood trees habitat conditions. Nodes with TinyOS were programmed to measure the environmental conditions (temperature, humidity and photo-synthetically active radiation) every 5 minutes and forwarded them through a multi-hop mesh network to a local base station. The data is sent from the base station to a computer located 70 Km away, through radio links. The nodes were programmed to run at a very low duty cycle to save energy.

A wireless sensor network was deployed to monitor eruptions at Tungurahua volcano, located in central Ecuador [31]. This single hop network is constituted by five sensor nodes where three of them are equipped with a specially constructed microphone to monitor infrasonic signals originated by volcanic eruptions. The data collected by the sensors are sent to a local sink and then relayed over radio links to a computer located 9 Km away. Mica2 nodes with TinyOS were used.

Measurement the microclimate in potato crops is the main goal of Lofar agro project [32]. The collected information will be used to improve the advice on how to combat phytophtora within a crop, based on the circumstances within each individual field. Phytophthora is a fungal disease in potatoes, their development and associated attack of the crop depends strongly on the climatologically conditions within the field. A total of 150 sensor nodes, similar to the Mica2 motes, were installed in a parcel for crop monitoring. Nodes are manually localized and their location registered on a map. Sensor nodes are equipped with sensors for registering the temperature and relative humidity. In addition to the sensor nodes, the field is equipped with a weather station to register the luminosity, air pressure, precipitation, wind strength, and direction. The sensor nodes use TinyOS operating system. The data collected by the sensor nodes is sended over a multi-hop routing protocol to the local sink node (field gateway) and further transferred via Wi-Fi to Lofar gateway. The Lofar gateway is connected via wire to the Internet and data is uploaded to a Lofar server and further distributed to a couple of other servers.

In SECOAS project [33] a sensor network was deployed at Scroby sands off the coast of Great Yarmouth and its purpose will be to monitor the impact of a newly developed wind farm on coastal processes in the area. New sensor hardware, based on MCU PIC 18F452 was developed in this project and a new operating system, designated by kOS (kind-of operating system) was proposed to run on it. The sensor nodes are equipped with sensors for registering the pressure, turbidity, temperature and salinity. Sensor nodes, base stations on the sea and land stations, form the hierarchical and single hop network. Nodes transmit their data to the sea base stations, which will then transmit the data to the land station. Base stations are sensor nodes equipped with additional functionalities, more power supplies and larger communication range. The data accessed from the land station via Internet.

Foxhouse [34] get real time information about the habitat of foxes in a fox house. A wireless sensor network in the Foxhouse case has 14 nodes organized in two clusters. The network uses FFD nodes to relay data and RFD nodes for sensing. The sink node is connected to a personal computer where data is stored. CiNet boards compliant with IEEE 802.15.4 and based on ATmega 128L MCU are used on sensing nodes. The sensing nodes are equipped with temperature, humidity and light sensors.

In Sensorscope project [35], two networks were deployed. The first network was installed in Wannengrat to study environmental processes involving snow. The second network was installed on a glacier in the canton Valais, Switzerland, to measure air temperature, air humidity, surface temperature, wind direction and speed, precipitation and solar radiation. Seven nodes were used in the first deployment and sixteen nodes in the second. The similar solutions were used on both deployments. A Shockfish TinyNode platform was chosen and it is composed by a Texas Instruments MSP430 MCU and a Semtech XE1205 radio transceiver, operating in the 868 MHz band. The sensing nodes and the sink node uses TinyOS operating system. A multi-hop network is used to support communications between the sink node and the sensing nodes. Sensing stations regularly transmit collected data (e.g., wind speed and direction) to a sink, which, in turn, uses a gateway to relay the data to a server. GPRS, Wi-Fi or Ethernet technologies can be used to connect the sink node to the data base server, which can be installed remotely. Data is published on a real-time Google Maps-based web interface and on Microsoft's SensorMap website.

VI. Challenges for Environmental Sensor Networks

The term Internet of Things [36] describes a vision in which networks and embedded devices are omnipresent in our lives and provide relevant content and information whatever the user location. Sensors and actuators will play a relevant role to accomplish this vision. Although, extensive efforts have been done to achieve the Internet of Things vision, there still some challenges that need to be addressed. The most relevant are presented bellow.

Power management. This is essential for long-term operation, especially when it is needed to monitoring remote and hostile environments. Harvesting schemes, cross-layer protocols and new power storage devices are presented as possible solutions to increase the sensors lifetime.

Scalability. A wireless sensor network can accommodate thousands nodes. Current real WSN for environment proposes the use of tens to hundreds nodes. So it is necessary to prove that the available theoretical solutions are suited to large real WSN.

Remote management. Systems installed on isolated locations cannot be visited regularly, so a remote access standard protocol is necessary to operate, to manage, to reprogramming and to configure the WSN, regardless of manufacturer.

Usability. The WSNs are to be deployed by users who buy them off the shelf. So, the WSN need to become easier to install, maintain and understand. It is necessary to propose new plug and play mechanisms and to develop more software modules with more user-friendly interface.

Standardization. The IEEE 802.15.4 represents a millstone in standardization efforts. Although, compatibility between of-the-shelf modules is in practice very low. It is important to specify standard interfaces to allow interoperability between different modules vendors in order to reduce the costs and to increase the available options.

Mesh routing support. The mesh networks topologies can both provide multi-hop and path diversity [40]. So, a routing protocol to support multi-hop mesh network is crucial [37], which must take into account the very limited features of the network.

Size. Reducing the size is essential for many applications. Battery size and radio power requirements play an important role in size reduction. The production of platforms compatible with the smart dust can be determinant in WSN environmental monitoring.

IP end-to-end connectivity. Originally it was not thought appropriate the use of IP protocol in WSN networks, because of the perception that is was to heavy weight to the WSN nodes resources. Recently, the industry and the scientific community start to rethink many misconceptions about the use of IP in all WSN nodes [38]. Supporting IPv6 on sensor nodes simplifies the task of connecting WSN devices to the Internet and creates the conditions to realize the paradigm of Internet of Things community. Additionally, by using IPv6 based protocols, users can deploy tools already developed for commissioning, configuring, managing and debugging these networks [37]. The application developing process is also simplified and open.

Price. Available sensor platforms on the market are expensive which precludes its use widely. Produce cheaper and disposable sensor platforms it is also a challenge.

Support other transducers types. Environmental monitoring usually uses limited type of transducers, such as temperature, light, humidity and atmospheric pressure. New environmental monitoring applications will be developed and new transducers will be necessary to measure new physical phenomena, for example image and video. Transmit images and video on resources and power constrained networks are a challenge [39].

The identified challenges must be addressed simultaneously by scientific community and by industry to create successful commercial solutions.

VII. Conclusions and Future Work

In this research work, a survey on environmental monitoring using wireless sensor networks and their technologies and standards was carried out. Some of the most relevant environmental monitoring projects with real deployments were analyzed and the conclusions used to identify the challenges that need to be addressed.

Wireless sensor networks continue to emerge as a technology that will transform the way we measure, understand and manage the natural environment. For the first time, data of different types and places can be merged together and accessed from anywhere. Some significant progress has been made over the last few years in order to bridge the gap between theoretical developments and real deployments, although available design methodologies and solutions are still relatively immature. As a consequence, widespread use of WSNs for environmental proposes is not yet a reality.

It is predictable that in the near future any object will have an Internet connection – this is the Internet of Things vision. In smart cities, the environmental data will provide usefully information to the citizens. For example, air quality, transportation information, emergency services, and so on. The citizens can access to this information via Internet.

Nowadays, the IP suite protocol support in environmental monitoring is inconsistent. It is necessary design new protocols and evaluates the existing ones. Assess the major benefits associated with the support of the IP protocol on all nodes, using simulation and testbeds is fundamental. This evaluation will be addressed as a future work.

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References

[1] J. Yick, B. Mukherjee, and D. Ghosal, “Wireless sensor network survey”, Computer Networks, Vol. 52, Issue 12, , pp. 2292-2330, August 2008

[2] IF. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “Wireless sensor networks: a survey,” Computer Networks; vol. 38, issue 4, pp. 393–422, 2002.

[3] R. Cardell-Oliver, M. Kranz, K. Smettem, and K. Mayer, “A Reactive Soil Moisture Sensor Network: Design and Field Evaluation,” International Journal of Distributed Sensor Networks, vol. 1, pp. 149-162, 2005.

[4] G. Barrenetxea, F. Ingelrest, G. Schaefer, and M. Vetterli, “The hitchhiker's guide to successful wireless sensor network deployments,” Proceedings of the 6th ACM conference on Embedded network sensor systems, 2008, Raleigh, NC.

[5] IEEE Std 802.15.4-2006. Part 15.4: wireless medium access control (MAC) and physical layer (PHY) specifications for low-rate wireless personal area networks (LR-WPANs). IEEE Std 802.15.4-2006, 2006.

[6] The IEEE std. 802.15.5-2009: Part 15.5: Mesh Topology Capability in Wireless Personal Area Networks (WPANs) IEEE Std802.15.5-2009, 2009.

[7] P. Baronti, P. Pillai, V. Chook, S. Chessa, A. Gotta, and Y. Hu, “Wireless sensor networks: A survey on the state of the art and the 802.15.4 and ZigBee standards,” Computer Communications, vol. 30, issue 7, Wired/Wireless Internet Communications, pp. 1655-1695, May 2007.

[8] F Zhao, and L. Guibas, Wireless Sensor Networks: An Information Processing Approach, Morgan Kaufmann: San Francisco, pp. 240–245, 2004.

[9] A. Reddy, P. Kumar, D. Janakiram, and G. Kumar, “Wireless sensor network operating systems: a survey,” Int. J. Sen. Netw, vol. 5, issue 4, pp. 236-255, 2009.

[10] TinyOS, http://www.tinyos.net/, [Jully 2010].

[11] Contiki, http://www.sics.se/contiki/, [Jully 2010].

[12] F. Garcia-Hernandez, P. Ibarguengoytia-Gonzalez, and A. Perez-Diaz, “Wireless Sensor Networks and Applications: A Survey”, IJCSNS International Journal of Computer Science and Network Security, vol. 7, issue 3, pp. 264-273, 2007.

[13] M. Pereyma, “Overview of the modern state of the vibration energy harvesting devices,” Proc. IEEE MEMSTECH, 2007, pp. 107-112.

[14] B. Chen, K. Jamieson, H. Balakrishnan and R. Morris, “Span: an energy efficient coordination algorithm for topology maintenance in ad hoc wireless networks,” ACM Wireless Networks Journal, vol. 8, issue 5, pp. 481–494, 2002.

[15] Y. Xu, J. Heidemann, and D. Estrin, “Geography informed energy conservation for ad hoc routing,” Proceedings of the 7th International Conference on Mobile Computing and Networking (MobiCom 2001), Italy, July 2001, pp. 70–84.

[16] ZigBee Alliance, Network Layer Specification 1.0, Dec. 2004.

[17] WirelessHART Webpage. Available from: http://www.hartcomm.org/, [Jully 2010].

[18] L. Nardis, and M. Benedetto, “Overview of the IEEE 802.15.4/4a standards for low data rate Wireless Personal Data Networks”, Positioning, Navigation and Communication, pp. 285-289, 2007.

[19] J. Al-Karaki, and A Kamal, "Routing techniques in wireless sensor networks: A survey", IEEE Wireless Commun. Mag., vol. 11, no. 6, 2004, pp. 6-28.

[20] Iris sensor platform, http://www.xbow.com/Products/productdetails.aspx?sid=264, [Jully 2010].

[21] TelosB sensor platform, http://www.xbow.com/Products/Product_pdf_files/Wireless_pdf/TelosB_Datasheet.pdf, [Jully 2010].

[22] Chipcon webpage, http://www.chipcon.com, [Jully 2010].

[23] Atmel Corporation. 2004. 8-bit AVR microcontroller with 128K bytes in-system programmable flash, http://www.atmel.com/dyn/resources/prod_documents/2549S.pdf, [Jully 2010].

[24] Texas Instrument. MSP43OX4XX Family, User Guide, Dallas, Texas, 2003.

[25] I. Akyildiz, and M. Vuran, Wireless Sensor Networks, New York: John Wiley & Sons, 2010.

[26] P. Levis, N. Lee, M. Welsh, and D. Culler, “Tossim: accurate and scalable simulation of entire tinyos applications,” in SenSys ’03: Proceedings of the 1st international conference on Embedded networked sensor systems. New York, NY, USA: ACM, 2003, pp. 126–137.

[27] F. O’sterlind, A. Dunkels, J. Eriksson, N. Finne, and T. Voigt, “Cross-level sensor network simulation with cooja,” In Proceedings of the First IEEE International Workshop on Practical Issues in Building Sensor Network Applications (SenseApp 2006), Tampa, Florida, USA, Nov. 2006.

[28] T. Arampatzis, J. Lygeros, and S. Manesis, “A survey of applications of wireless sensors and wireless sensor networks,” in Proc. 13th Mediterranean Conf. Control Automation, Cyprus, Turkey, Jun. 2005, pp. 719–724.

[29] R. Szewczyk, A. Mainwaring, J. Polastre, and D. Culler. “An analysis of a large scale habitat monitoring application,” In Proceedings of the Second ACM Conference on Embedded Networked Sensor Systems (SenSys), Baltimore, November 2004.

[30] G. Tolle, J. Polastre, R. Szewczyk, D. Culler, N. Turner, K. Tu, S. Burgess, T. Dawson, P. Buon- adonna, D. Gay, and W. Hong, “A Macroscope in the Redwoods,” In: Proceedings of the 3rd ACM International Conference on Embedded Networked Sensor Systems (SENSYS), ACM Press, San Diego, CA, USA, pp. 51–63, November 2005.

[31] G. Werner-Allen, K. Lorincz, M. Welsh, O. Marcillo, J. Johnson, M. Ruiz, and J. Lees, "Deploying a Wireless Sensor Network on an Active Volcano," IEEE Internet Computing, pp. 18-25, March/April, 2006

[32] Lofar project, http://www.lofar.org/p/Agriculture.htm, [July 2010].

[33] M. Britlon and L. Sacks, “The SECOAS project: Development of a self organizing. Wireless sensor network for environmental monitoring”, 2nd International Work5hop on Sensor and Actor Network Protocols and Applications, August 2004.

[34] I. Hakala, M. Tikkakoski, and I. Kivela , “Wireless sensor network in environmental monitoring - case foxhouse,” in Proceedings of the Second International Conference on Sensor Technologies and Applications (SENSORCOMM 2008), Cap Esterel, France, August 25-31 2008.

[35] G. Barrenetxea, F. Ingelrest, G. Schaefer, M. Vetterli, O. Couach, and M. Parlange, “SensorScope: Out-of-the-Box Environmental Monitoring,” Proceedings of the 7th international conference on Information processing in sensor networks, pp.332-343, April 22-24, 2008

[36] N. GershenfeldN, R. Krikorian, and D. Cohen, “The Internet of Things,” Scientific American 2004; vol. 291, issue, pp. 76-81.

[37] N. Kushalnagar, G. Montenegro, and C. Schumacher, “IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals,” Request for comments 4919, IETF, August 2007.

[38] J. Hui, and D. Culler, “Extending IP to Low-Power, Wireless Personal Area Networks,” IEEE Internet Computing 2008, vol. 12, issue 4, pp. 37-45.

[39] L. Zhou, N. Xiong, L. Shu, A. Vasilakos and S.-S. Yeo, “Context-Aware Multimedia Service in Heterogeneous Networks,” IEEE Intelligent Systems, vol. 25, no. 2, Mar./Apr. 2010, pp. 40-47.

[40] L. Zhou, X. Wang, W. Tu, G. Mutean, and B. Geller, “Distributed Scheduling Scheme for Video Streaming over Multi-Channel Multi-Radio Multi-Hop Wireless Networks,” IEEE Journal on Selected Areas in Communications, vol. 28, no. 3, pp. 409-419, Apr. 2010.

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