# A Wireless Sensor Network for Smart Irrigation and Environmental Monitoring: A Position Article

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## Abstract

Traditional instrumentation based on discrete and wired solutions, presents many difficulties to measure or to compute plant physiological responses due to the large geographical areas that may be involved. This paper describes an implementation of a wireless sensor network for agriculture low data-rate applications. This network includes several solar powered wireless acquisition stations used on soil moisture measurements in greenhouses and open field crops in order to improve irrigation efficiency. Soil moisture is sensed by using the dual-probe heat-pulse method. Climate parameters such as air and soil temperature, solar radiation and relative humidity are also measured. After acquisition, data is routed to a base station where it is stored, analyzed and used to perform local control tasks. The network protocol uses a combination of TDMA (Time Division Multiple Access) and CSMA (Carrier Sense Multiple Access) techniques to allow easy deployment and to provide plug-in capabilities to the in-range acquisition stations. The out-range units employ a zone routing protocol where data flow converges to the in-range units, which are also responsible for data aggregation. It is also discussed actual trends in miniaturization, and how each acquisition node is being replaced by a CMOS single-chip, with a built-in soil moisture micro-sensor with wireless capabilities. Following the plant instrumentation approach, specific solar powered microsystems provide a convenient way to acquire several important parameters from the plant themselves. However, as their size and cost decreases, effective power supplies become a larger problem.

*Key words*: Wireless Network, Soil-Moisture Sensor, Networking protocols

## 1 Introduction

Efficient management of agricultural processes requires field data acquisition systems as well as many and specific sensors to estimate crop growth. Despite this requirement to achieve competitiveness on the market, most of Portuguese greenhouses facilities do not employ or explore the full capabilities of modern digital control systems. This fact is related to several factors, such as the cost and the difficulty to operate and integrate the available solutions. However, recent advances in electronics, microelectronics, communications and information technologies allow the implementation of low cost, easy operating and virtually free maintenance agricultural field data acquisition systems.

In this paper we propose a wireless network with a top-down hierarchy structure, the most suited for agricultural-related applications such as environmental monitoring and smart irrigations systems. For the lowest level – the sensor level – a wireless network based on a narrow-band RF link is proposed, the protocol being based on the time slotting concept where data is routed to a base station.

## 2 Wireless network architecture

While developing field data acquisition systems for agricultural environments, some key features must be ensured, such as:

- Device mobility – to overcome agricultural activities constrains;
- Automatic device connection/registering in the network;
- Routing capabilities – to ensure device access even with temporary/permanent failure in some network branches;
- Power Management.

To fulfill these features, the network global architecture has a top-down hierarchy, as depicted in Fig. 1. Data acquisition is performed by using solar powered wireless acquisition stations, denoted as SPWAS (Morais *et al*, 1996), connected in a mesh topology. A zone routing protocol is used to establish a link between each SPWAS. For all units that are in-range in respect to the base station (BS) or to a DAP (Data Access Point), a network protocol based on the time slotting concept is employed. At a higher level, BS and DAP units may support other protocols such as the 802.11 (Wi-Fi), Bluetooth and modem-based connections (GSM or GPRS), to expand network access, data gathering and management functions.

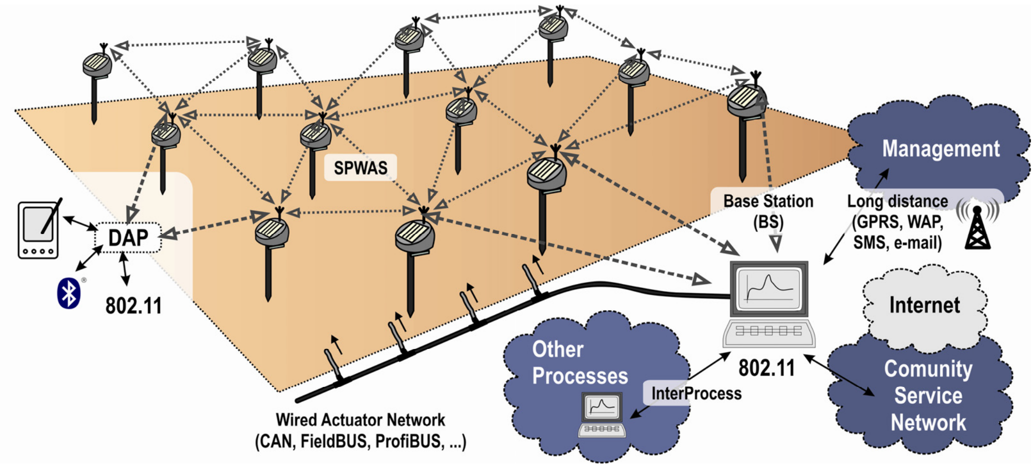

Fig.1 – Network architecture.

## 3 Acquisition stations

These stations are currently being used to collect data and to perform data routing between other SPWAS and the base station. Since mobility and low-cost is a demand in commercial agriculture facilities, the stations were developed using low-cost electronics and assembled on an ABS enclosure (commonly used on commercial solar power garden light) that could be easily installed, Fig. 2. Input capabilities are 16 analog-channels with 12-bit resolution and 4 16-bit counters for frequency measurements. Sensors that have been used were the LM50B temperature sensor (National Semiconductor), HybridCap relative humidity sensor (Panametrics, Inc.) and the TSL230 solar radiation (Texas Instruments). The tip of each station pole (the part that stays under ground) was provided with two needles as a soil moisture sensor. Communications are based on a low-power radio frequency link provided by BiM-433F transceivers (Radiometrix) operating in the 433.92 MHz ISM band with a 150 m coverage range.

Power is primarily provided by the built-in solar panel, which is also used to charge five AA-size 600mAh NiCd batteries running as a backup power system. Special care has been taken to maximize solar power conversion efficiency regarding battery charging and powering the system. By recharging the batteries with a “bang-bang” control (delivery of small packets of charge), the charging circuit maintains maximum power transfer to the NiCd cells, thus achieving an efficiency of almost 85%. The system’s main supply (5V) is then provided through a single-ended primary-inductance converter (SEPIC) that allows battery voltages both below or above the output voltage.

Fig.2 – Photograph of a SPWAS station inside a greenhouse.

In Fig. 3 it is shown climate data (temperature, relative humidity and solar radiation) acquired by one SPWAS station located inside a greenhouse during a week in winter. The acquisition period was one minute. Besides climate data, battery and solar panel voltages were also measured, Fig. 4. When battery voltage falls below a specified threshold, data routing is disabled and the acquisition period becomes larger to reduce power consumption and thus prevent SPWAS shutdown.

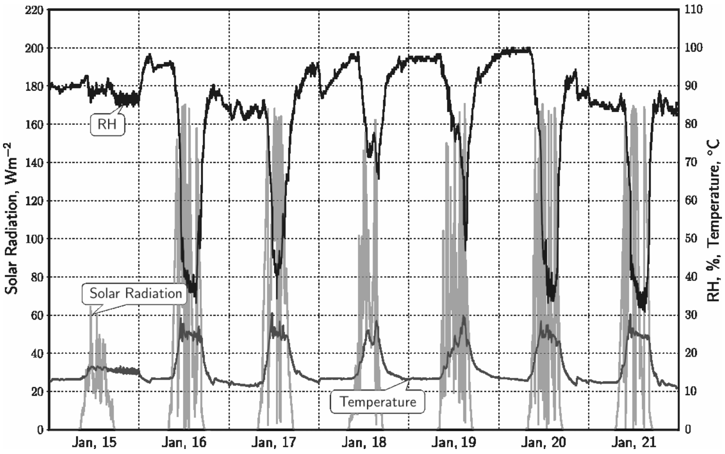

Fig. 3 – Climate data from a SPWAS inside a greenhouse during one week (winter and cloudy days).

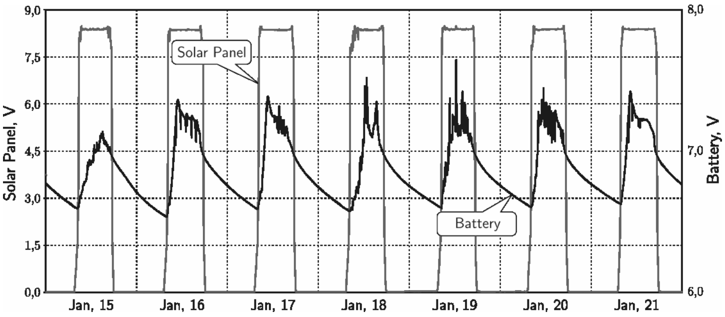

Fig. 4 – SPWAS solar panel and battery voltages evolution during one week.

## 4 Soil moisture sensor

The sensor used for soil moisture measurements is a dual-probe heat-capacity (DPHC) sensor that can make simultaneous measurements of soil temperature and water content (Campbell *et al.*, 1991; Tarara *et al.*, 1997). The sensor consists of a small plastic body with two parallel hypodermic needle probes spaced 6 mm apart and extending 30 mm from the body, Fig. 5 (Valente *et al.*, 2004).

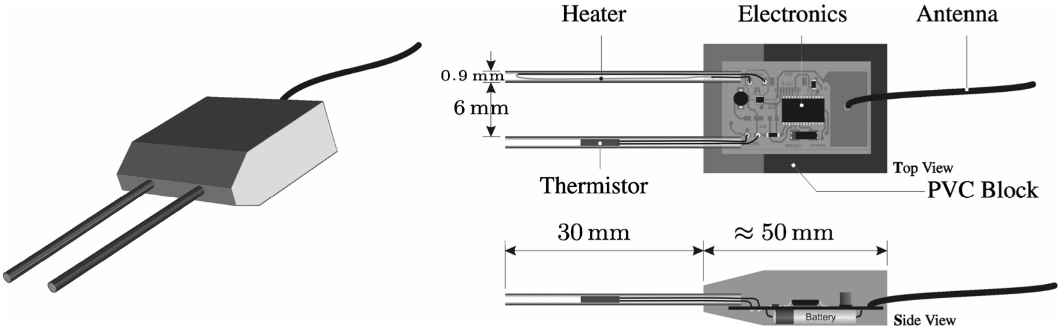

Fig. 5 – Perspective of the developed soil moisture sensor;

The soil moisture is determined by applying a heat pulse (e.g. 8 s) and measuring the maximum temperature rise at the thermistor probe for about 60 s, Fig. 6. Soil water content,θ, (volume of water per volume of soil – $m^3m^{-3}$) can then be estimated as:

$$\theta = \frac{\frac{q}{\pi \exp r^2 T_{max}} - 1.92\frac{\rho_b}{\rho_p} - 2.5X_O}{4.18} \quad (1)$$

where, $q$ is the applied energy per length of probe (J $m^{-1}$), $r$ is the distance between hypodermic probes (m), $T_{max}$ is the maximum temperature rise at the thermistor probe (K), $\rho_b$ is the soil bulk density (kg $m^{-3}$), $\rho_p$ is the soil particle density (2650 kg $m^{-3}$) and $X_O$ is the organic matter fraction.

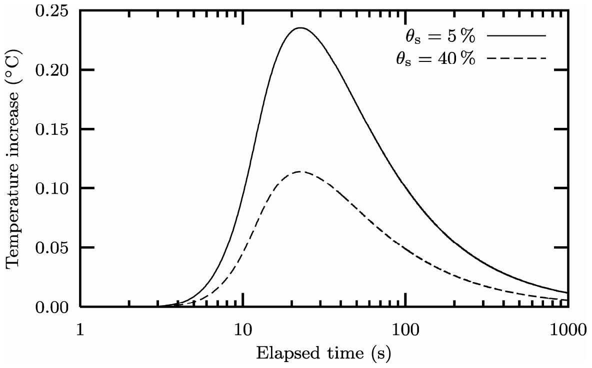

Fig. 6 – Soil moisture sensor response to distinct soil water content.

## 5 Network protocol

At a first stage, a sensor network has been built using SPWAS connected in a star non-slotted network. With this topology the network span was very limited and so it was difficult to integrate other applications, such as open-field irrigation systems. Another key factor was data routing between each SPWAS and the base station. In the star topology, data was acquired upon command request issued by the base station. In order to expand network span, this simple protocol has to be adapted to allow many more nodes that were out-of-sight from the base station. Data should then be routed through other SPWAS stations. This requirement has changed radically the network routing scheme.

Currently, a network routing protocol is being tested as a sensor wireless network. The communications protocol is based on TDMA modified to allow slot dynamic attribution and master functions. One of the major modifications in respect to fully implementation of TDMA is the inclusion of a CSMA slot, which every station can use to request a time slot. Error control and data flow mechanisms can be simplified since there is no interference between nodes due to the slotting scheme. Basically, the RF narrow-band protocol is reduced to the implementation of a Media Access Protocol (MAC) necessary to ensure network efficiency.

The proposed protocol combines TDMA and CSMA techniques as depicted in Fig.7. Synchronization means have been incorporated in the GAP field. By using this mechanism, each node when detecting the sync field resets its own internal counter that will set its access time. SLOT 0 is, by default, owned by a base station and it is periodically generated to promote synchronization with acquisition stations. If, by any reason, the system needs to be restarted, the previous slot sequence is lost. However, another slot sequence is generated when each acquisition station become registered. Furthermore and due to the fact that each acquisition station can monitor the prior slot, if some slot-N was not used, the current station (N+1) can always use the slot of station N. By using a combination of TDMA and CSMA, each network node has a plug-in feature based on message service rather than addressing a physical device, enabling an automatic insertion/removal procedure (Serôdio *et al.*, 1998). With this scheme, a high level of flexibility can be achieved allowing easy deployment and reducing to a virtually no maintenance of low-level network nodes.

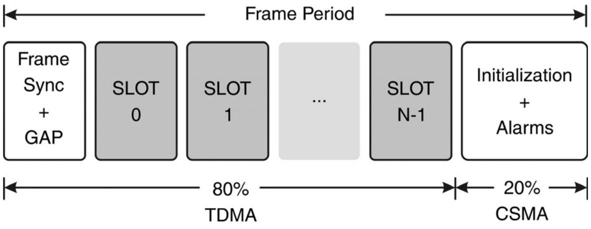

Fig. 7 – Medium access using TDMA and CSMA techniques.

## 6 Current developments and discussion

Modern control strategies, based on plant development, require data from the plants themselves. Some examples are parameters such as water content at root level, nitrates and pollutants concentration, solar PAR radiation, $CO_2$ concentration and water and nutrients fluxes in the stem.

A low-power microsystem with wireless capabilities is a suitable solution for these measuring purposes, allowing a new-concept: plant instrumentation. Fig. 8 shows a microsystem, implemented in CMOS technology as a Multi-Chip-Module (MCM), used to soil moisture and temperature measurements. Basically, it features a micromachined sensor with an integrated temperature sensor and heater, and a CMOS mixed-signal interface. After applying a heat pulse, temperature rise is measured by the on-chip temperature sensor and digitized using a second-order switched-capacitor fully differential delta-sigma modulator. Communications are provided by the on-chip transmitter, operating at the 433.92 MHz ISM band (Morais *et al.*, 2004).

As the size and cost of such wireless sensor nodes (to be used in smart irrigation systems and environmental monitoring) decreases, the likelihood of their use becoming widespread in the environment increases. This reduction in size has led to a large research effort based around the vision of ubiquitous networks of wireless sensors (Rabeay *et al.*, 2004) that are simply deployed in the environment.

The issue is that the scaling down in size of CMOS electronics has far outpaced the scaling of energy density in batteries, which are by far the most prevalent power supply currently used. Besides, communications and the heat-pulse technique used in the soil moisture sensor are the major parcels of total power consumption and should be minimized. In the present research, effective power supplies still constitute one of major problems that are being currently addressed.

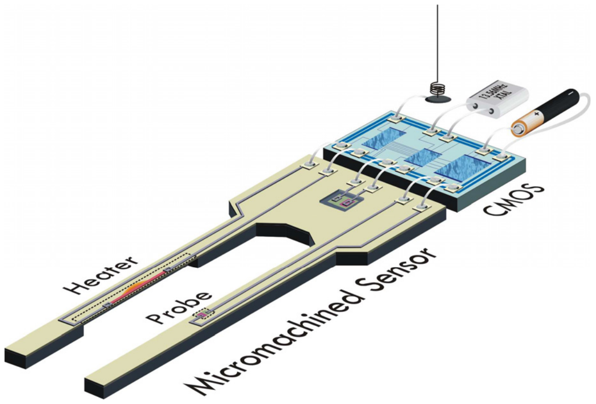

Fig. 8 – Multi-Chip-Module: A micromachined soil-moisture sensor with a CMOS Wireless interface.

## 7 Conclusions

Nowadays, wireless standards are being applied with the aim of reaching a higher level of integration and to access data in real time, worldwide. Some examples are the use of video, local access through PDA and data exchange using GPRS and 802.11 (Wi-Fi). However, sensor applications characterized by low to medium resolutions and bandwidths below 2 kHz are still a major challenging issue when designing a network that could have thousands nodes executing different acquisition functions and maintaining network data routing.

Agriculture field data acquisition systems presents several issues related to size, cost, power consumption and networking of a particular solution. By using a low-power, low-size microsystem to acquire climate data and plant physiological responses it will be possible to spread micronodes across a large geographical area. Particularly, the microsystem for soil moisture measurements using the Dual-Probe Heat-Pulse has showed to be the most appropriate to measure humidity at different soil depths, and therefore, close to plant roots in a non-destructive and automated manner.

## 8 References

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