Design of a low power wireless sensor network platform for monitoring in citrus production

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Abstract

Wireless sensors networks (WSN) enable the acquisition of valuable data directly from the production field that, in turns, open unprecedented opportunities for data analysis and decision making systems. Monitoring microclimate variations, typical in citrus crops, could allow precise irrigation scheduling and harvest planning. However, a limited lifetime of battery-powered sensor nodes may impose barriers to its widespread adoption. This work presents the overall architecture and main characteristics of a WSN solution based on open standards and free software. The main techniques applied to reduce power consumption are described, obtaining an expected node battery lifetime of more than two years.

1 Introduction

Informed management of agricultural production requires distributed data of relevant conditions across the producing fields. Advances in embedded systems and communications technologies make possible to monitor distributed measurement points with the following characteristics. Wireless nodes are low cost enough so that a dense measurement array can be deployed. Two additional characteristics are key for providing an easy to use service to agricultural technicians and producers. The nodes need to have very low power consumption so that they operate during long periods (several months to more than one year) without changing batteries or by harvesting energy from the environment. The hardware, software and the communication protocols need to be reliable and robust so that seamless network setup and unattended operation are possible. Several wireless sensor networks (WSNs) have been applied to precision agriculture for irrigation systems [1, 2], and frost detection [3].

This work presents the overall architecture and main characteristics of a complete solution being tested in an actual production context. The proposed solution is based on open standards and free software and the main techniques applied for autonomous, low power operation are summarized. The solution is being tested in a citrus farm for the following goals. First, irrigation monitoring aiming at efficient use of water and energy. Second, monitoring of microclimate conditions, mainly for frost detection. In the case of citrus, production fields with significant topographic variations are common. This leads to irrigation and microclimate variation along the production field. Both have important consequences on how the production is handled, either irrigation management decisions or harvest decisions (related to frost impact) or even extent of pesticide use. The presented system provides the producer with timely and detailed information for decision making based on data available online. A pilot network is being deployed in a citrus orchard in Margat, Canelones in the south of Uruguay.

2 Design

Fig. 1 depicts the overall system architecture. Sensor nodes form a wireless ad-hoc network based on IEEE 802.15.4 operating in the unlicensed 2.4 GHz band. Sensor nodes measure and report environment data to the network root node of the gateway. The gateway has both IEEE 802.15.4 and 3G connectivity, thus send the sensor information to a remote server in Internet via cellular network. Remote users

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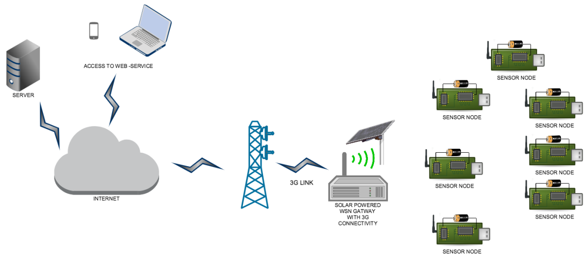

Figure 1: System architecture

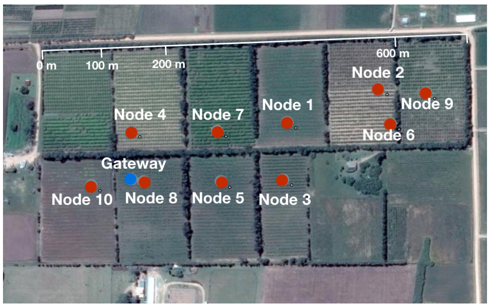

Figure 2: Image of citrus crop and sensors locations.

can access the information from their cellphones or personal computers by accessing a web service in Internet. Fig. 2 shows the actual location of sensors nodes and the gateway. The network currently has ten sensor nodes, deployed one per frame, each about one ha, thus the distance between sensors is roughly 100 m.

2.1 Hardware

The sensor node core is a CC2538 System-on-Chip (SoC) manufactured by Texas Instruments, which integrates an ARM Cortex-M3-based microcontroller with an IEEE 802.15.4 radio. The EMB-Z2538PA module by Embit was used for the PCB custom made design, which includes a CC2538 and a CC2592 PA/LNA front end delivering a RF output power up to $+20$ dBm. The node is powered by two AA lithium-ion or standard Alkaline batteries in series, supplying a nominal voltage of 3.0 V. We adopted the TPS62740 step-down DC-DC converter to reduce the node power consumption, which achieves efficiencies greater than 90% for a current drawn as low as $10\mu A$. This guarantees savings even during very low power drain, typical of the microcontroller low-power modes.

The node is equipped with the following sensor set: soil humidity (Decagon EC-05), air temperature and humidity (SHT-21 from Sensirion) and soil temperature (TMP275 from Texas instruments). The node and antenna are packaged in a IP65 case that is easily mounted on a pole made with a standard galvanized water pipe to connect with sensors in a meteorological shield and sensors on the ground. The gateway includes a single-board computer (Raspberry PI (RPI) model B+ v1.2), the sensor network root node and a 3G cellular modem. The gateway power supply system is comprised by a 50W solar-panel, a 12V 24Ah VRLA battery, and a solar charge controller. The photovoltaic system is designed to endure a couple of null solar generation days (cloudy sky in winter) for the worst case power consumption (low signal strength in 3G modem), providing a high autonomy even in bad climate conditions.

2.2 Embedded software and communication stack

Contiki is an open source, event-driven operating system oriented to WSN and IoT applications using constrained hardware. Contiki manages the hardware resources and includes different libraries such as network stacks. The Contiki distribution includes the network protocols' stack most widely used in WSN, described next. The physical and MAC layers are based on the standard IEEE 802.15.4. 6LowPAN is an adaptation layer protocol by the IETF (RFC 4944 and 6282) that allows the transport of IPv6 packets over 802.15.4 links. It is in charge of the compression of IPv6 and the upper layer headers and of the fragmentation and reassembly of IPv6 packets. RPL is the adopted routing protocol based on a tree-oriented strategy (RFC 6550), in which nodes join the network dynamically forming a mesh, and traffic flows to a root node.

The Constrained Application Protocol (CoAP), at the application layer, is a RESTful protocol for use with constrained hardware such as WSN nodes, since uses UDP underneath. The REST model works with server nodes that make certain resources available under a URL, allowing to have a client / server architecture based on a standard protocol. Client nodes access resources using methods such as GET, PUT, POST, etc. In this work we use the OBSERVE mechanism, which allows client nodes to retrieve a resource value from a server (GET) and keep it updated over a period of time.

The overall architecture, which is based on widely used standards and open protocols, allow to take profit of several freely available tools (e.g. simulator, protocol analyzer, framework).

The gateway runs an embedded Linux operating system (Raspbian Jessie distribution), that allows to execute the scripts or daemon that rely the wireless sensor network data to a server through Internet. The server side of the application and user software is treated on a companion paper.

2.3 Low power design techniques

A very low power consumption is achieved thanks to several design decisions. In the communication stack, the use of 802.15.4 with duty cycling through the ContikiMAC protocol allows the system to be over 97% of the time in low power mode. Also the use of appropriate protocols at higher layers (e.g. CoAP) allows to keep low power consumption. Regarding the node power management, Contiki takes full advantage of the microcontroller low power modes, powering down the microprocessor when there is neither processing needed nor events scheduled in the event queue.

When the sensors are idle, they are turned off through low leakage switches to lower its power drain. Additionally, the supply voltage of the node is lowered to further reduce the overall power consumption. The microcontroller optimal supply voltage to minimize the power consumption is 2.1V, but some sensors require a minimal power supply of 2.5V. The selected DC-DC converter has selectable output voltage. The microcontroller dynamically control, using an output pin, the supply voltage. While sensors are active and measuring the supply voltage is selected to 2.5V, and remaining time to 2.1V. As a result, the microcontroller active current is reduced from 1.3mA @ 2.5V to 1mA at 2.1V. With this technique, we also avoided power hungry level shifter stages to interact with the sensors. Finally, a careful setting of the I/O state of microcontroller pins in order to minimize consumption during sleep mode due to open inputs and pull ups / pulls downs. This performance gives an expected node battery longevity of more than two years in a leaf node that transmits sensor data every 15 minutes powered by batteries with 2.8Ah useful charge.

On the gateway side, the 3G modem is connected to the RPI via USB through a specially designed circuit that allows switching the power supply of the modem. Turning off the modem when it is not transmitting (75% of the time by design) results in a 16.5% reduction in the overall power consumption. This also acts as prevention in case of a potential hung up of the modem.

3 Conclusion and future work

The overall architecture of a WSN infrastructure for precision agriculture was presented. A reliable operation and reduced power consumption is mandatory to run unattended for years. This work summarized the main techniques applied to extend sensor node's battery longevity up to an expected lifetime of two years. A pilot was deployed in a real citrus orchard for testing purposes and subsequent validation. This kind of platform constitutes the basic infrastructure at the very early stage of a future decision support system.

References

[1] O. Adeyemi, I. Grove, S. Peets, and T. Norton. Advanced monitoring and management systems for improving sustainability in precision irrigation. *Sustainability*, 9(3):353, 2017.

[2] J. A. López, F. Soto, J. Suard'ıaz, P. Sánchez, A. Iborra, and J. A. Vera. Wireless Sensor Networks for Precision Horticulture in Southern Spain. *Comput. Electron. Agric.*, 68(1):25–35, Aug. 2009.

[3] F. J. Pierce and T. V. Elliott. Regional and On-farm Wireless Sensor Networks for Agricultural Systems in Eastern Washington. *Comput. Electron. Agric.*, 61(1):32–43, Apr. 2008.