Multi-sensor IoT architecture for monitoring of greenhouse parameters using Wireless Sensor Networks ⋆

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Abstract. As a consequence of deployment advantages of the Wireless Sensor Networks, the environmental monitoring of greenhouses parameters have been a widely used scenario for this technologies as a branch of the Precision Agriculture. In this research we propose an IoT architecture for this particular application. A Wireless Sensor Network (WSN) is designed based in the Zolertia Z1 mote, for the collection of luminous intensity, air temperature, soil moisture and relative humidity in different points of actual greenhouses. It is also developed, a Raspberry Pi 3 model B IoT Gateway based in the ThingsBoard IoT Gateway platform. It is implemented in this gateway basic data pre-processing and data persistence capabilities giving the application some Fog Computing features. At the cloud level is implemented a ThingsBoard cluster platform which could access the information about the network devices through the MQTT protocol. A dashboard is designed in order to monitor the environmental parameters and to test the given proposal.

Keywords: Internet of Things · Fog Computing · Wireless Sensor Networks.

1 Introduction

Nowadays, one of the most important trends of the Internet as a global communication platform, is the interconnection of machines and intelligent objects in order to integrate, reason, calculate and coordinate actions. Since the inception of the Internet of Things (IoT) idea around 2009[1], when more devices than people where connected to the Internet, the growth in this number has been exponential, predicting to reach the 50 billion of devices threshold near 2020.

One of the most attractive technologies within the IoT phenomena, are the Wireless Sensor Networks (WSN), due to its deployment capabilities in applications where powering sensors through a wired line is complex and unfeasible.

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Several research have been aimed to improve this networks in fields like communications and energy efficiency/harvesting [2].

Specifically, agriculture worldwide have been influenced by these technological paradigms. Precision Agriculture (PA) arises with the development of a new set of technologies for the supervision of the crops physical, chemical and climatic conditions, in order to optimize the production process and the final quality of the products [3, 4].

Greenhouses are a pillar of modern agriculture. These are artificial structures built in order to protect the crops from climatic conditions or minimize the effect of plagues. This controlled environment is an efficient way to control the conditions that affects the plant growth, resulting in better yields.

This proposal is aimed to implement a cloud based IoT system for monitoring greenhouses environmental parameters. The design takes into account the capability in a near future of including artificial intelligence algorithms, which can yield prediction models of plant growing, plant irrigation needs or even production volume of the greenhouses.

By the other hand, it turns interesting to include in this proposal some Fog Computing paradigm features. The main idea is to descend some processing power from the cloud to the edge devices of the network. Several research have been conducted in this topic as it is stated in [5]. We use a Raspberry Pi based IoT Gateway with a ThingsBoard Gateway platform installed. This allows to develop some useful features such as the IoT database interaction, data filtering, pre-processing and buffering and and also run future pre-trained artificial intelligence algorithms.

The results obtained in this research are the outcome of the collaboration between the universities associated to the VLIR UOS project of the Region of Flanders in Belgium and the Cuban entities of the Universidad Central "Marta Abreu" de las Villas, the Centro de Automatización Integral (CEDAI) Company and the Ministry of Agriculture (MA).

The rest of this paper is organized using the following structure. Section 2, establishes the hardware architecture used in this proposal. Section 3, is related to the software tools and platforms needed to makes this a functional and coherent system. Section 4 is dedicated to the experimental outline and results of the real implementation on the greenhouses. Finally, in Section 5 the concluding remarks and future research directions are presented.

2 Hardware IoT architecture for greenhouse monitoring

We develop a three layer hardware architecture as is logically defined in Fig. 1. The first layer is composed by a WSN, implemented in order to acquire the environmental parameters of this application. The fundamental roles of the wireless devices are measurement nodes and a network coordinator. Measurement nodes are distributed within the greenhouses and the coordinator is located in the ferti-irrigation pumping station connected to the IoT Gateway trough USB. The IoT

Gateway is the second logical layer of this architecture. It collects all the environmental sensed parameters of the greenhouses and send them through the Internet to a cloud-based IoT platform(Third Layer) which is installed at the UCLV facilities.

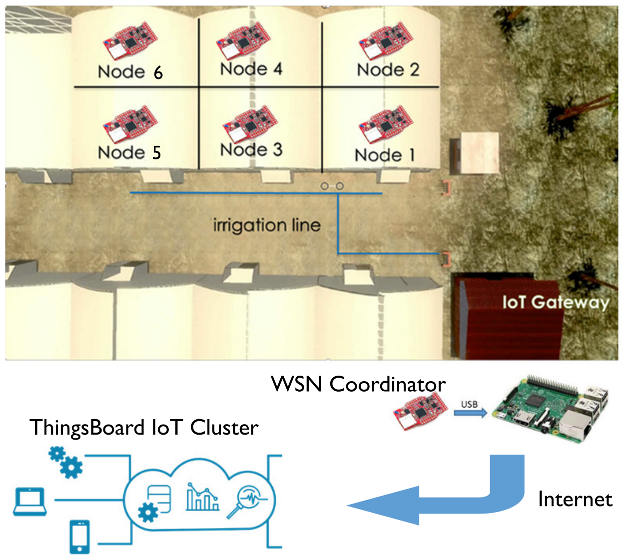

Fig. 1. Logical hardware architecture

2.1 Sensors

The environmental parameters selected by the experts to be measured in the greenhouses are the relative humidity, soil moisture, environmental temperature and luminous intensity. The low cost sensors presented in this solution, have acquisition libraries available on the free software community, and also standard connection and communication interfaces [6, 7] as is shown on Table 1.

Table 1. Low cost sensors used in the sensor nodes.

	Temperature/Relative Humidity	Soil Moisture	Luminous Intensity
Sensor model	DHT22	YL-69	LDR
Power	3.3 to 6 VDC	3.3 to 5 VDC	3.3 to 5 VDC
Interface	Digital	Analog, 0 to 4 V	Analog, 0 to 4 V
Operating Range	(0 to 100%)(-40 to 80°C)	(0 to 100%)	(0 to 10000 lux)

2.2 The Z1 Mote

The Z1 platform has been selected as wireless node for the proposed WSN. It has a widely used radio transmitter (CC2420) and is compatible with both IEEE 802.15.4 and 6LoWPAN 1 and ZigBee [8]. The integrated microcontroller in this board is the second generation MSP430, which has 16 bits and ultra low power consumption. To power this device is possible through USB or batteries (AA or AAA). Figure 2, depicts the logical hardware setup for the measurement nodes in this proposal.

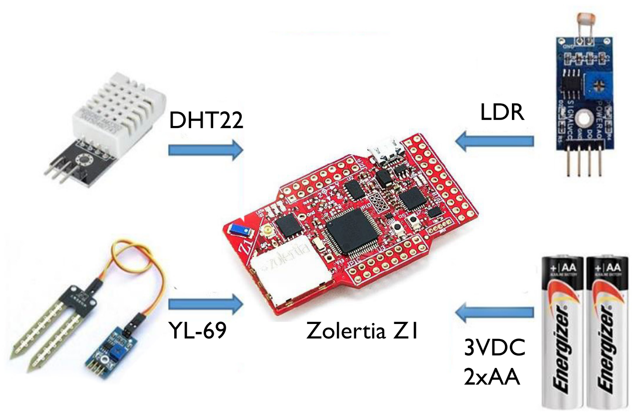

Fig. 2. Measurement Node Architecture

2.3 IoT Gateway

This logical layer of the network is composed of a Raspberry Pi 3 Model B connected via Ethernet to a Wi-Fi router that can provide connectivity to the Internet. Implemented on this computer, there is a IoT gateway platform that manages the values of the greenhouse environmental variables, received from the coordinator node through USB serial connection.

3 Software Architecture

3.1 Wireless sensor network

The wireless sensor network that collects the information from the greenhouses to the IoT Gateway is based on ContikiOS v3.0, an operating system for embedded devices. In ContikiOS, the TCP/IP networking stack has been adapted

Table 2. Network stack

Application	Collect-View (Nodes periodically send packets with information about the network performance)
Transport	User Datagram Protocol (UDP) (Client-Server model)
Network	IPv6, RPL (with ETX[3]as routing metric), 6LoWPAN
MAC	TSCH/Orchestra
Physical	IEEE 802.15.4 (CC2420, IEEE 802.15.4 standard-compliant radio)

to the small memory and processing capacities of the sensor nodes. The application created for this application is composed by the protocol stack presented in Table 2, and described in the following paragraphs.

At the physical layer, the 2.4 GHz band specified in the standard IEEE 802.15.4 [9] for Low-Power and Lossy Networks (LLNs) is used. The CC2420 available in the Zolertia Z1 platform complies with this standard. At the Medium Access Control (MAC) layer, the application uses the Time-Slotted Channel Hopping (TSCH) mode specified in the standard IEEE 802.15.4 [9], as implemented in ContikiOS. In this mode of operation, time is divided into slots and the duration of each slot is sufficient to send a maximum length data packet and receive the corresponding ACK. In every slot, three actions are possible: transmit, receive and sleep.

Slots are grouped into time-slotted frames, called slotframes, which repeat periodically over time. Duty-cycling is achieved by introducing sleeping slots in every slotframe. All nodes are synchronized to a given slotframe and multiple slotframes can coexist. Synchronization information is included in all packets. The multichannel operation is based on deterministic channel hopping. For more details on TSCH, see REFTSCH. The problem of creating the schedule for the nodes to communicate with each other is considered out of the scope of the standard. In this application, a collection-oriented scheduling algorithm called Orchestra is used. Orchestra [10] autonomously creates and maintains TSCH schedules at the nodes using information from the routing tree. The schedule is composed of multiple slotframes, each one dedicated to a particular type of traffic, e.g. application level communication, routing signaling, and TSCH control frames. The slotframe length can be tuned to create a trade-off between throughput, network latency and power consumption. Orchestra is implemented in ContikiOS.

At the network layer, the IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) [11] is the *de facto* routing standard for LLNs. RPL creates a routing tree towards the sink in the form of a destination-oriented directed acyclic graph (DODAG), thus defining parent-children relationships along the gathering tree. RPL manages and maintains the routing tree adapting it to adverse conditions such as the disconnection of a node caused by the depletion of its batteries. The IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) [12] allows encapsulation and header compression for IPv6 packets such that they can be sent using small link-layer frames.

Though both the Transmission Control Protocol (TCP) and the User Datagram Protocol (UDP) could be used in LLNs, the application presented here relies on UDP traffic (e.g. CoAP), in order to avoid the high control overhead generated by TCP. In this application, the coordinator acts as UDP server and sensor nodes send data packets on a periodical basis towards the server.

3.2 ThingsBoard Platform

Several open software platforms are available online for data collection and management of IoT applications [13]. For the implementation of this particular architecture, we have selected ThingsBoard Java 8 based platform, using the general hierarchy and architecture depicted in Fig. 3.

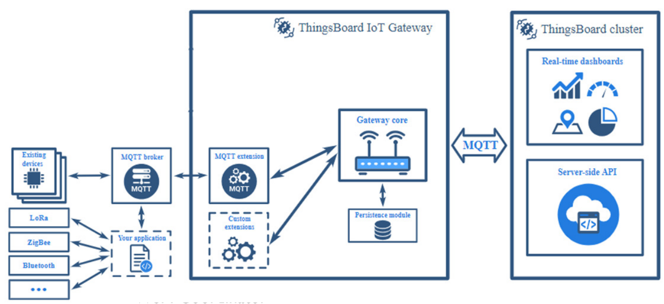

Fig. 3. ThingsBoard IoT architecture in this proposal

The ThingsBoard IoT Gateway platform is installed at the Raspberry Pi, granting access to all the wireless nodes via Message Queue Telemetry Transport (MQTT) protocol, which is a lightweight communication protocol based on the publish/subscribe paradigm and is originally intended for small devices [14].

This Gateway platform provides simple integration APIs to encapsulate common tasks such as: local data persistence and delivery, message converter/adapters and device connection. It uses a MariaDB database in the Raspberry Pi to make a temporal buffer of all the measured variables. The available time series are pre-filtered, creating some containers called assets, to reorganize data. There is also implemented a cloud data upload schedule in order to advantage of the hours with the lower network traffic. All this features are developed and designed through a rule chain workflow available at the same platform.

All this pre-processing data performed at the gateway is consistent with the Fog Computing paradigm, and release the cloud services of taking care of this in difficult cloud connectivity environments.

The same MQTT protocol is used to communicate the gateway with a ThingsBoard cluster application as an external agent. This is performed using Apache Kafka plugin, which is a messaging queue system originally designed

to manage big amount of data [15]. This tool is used to connect the gateway with Big Data modules of the cloud platform.

4 Experimental results

The proposed architecture was implemented and tested in actual greenhouses owned by the "Empresa de Cultivos Varios Valle del Yabu", near to the city of Santa Clara in Cuba.

A total of 6 measurement nodes were placed uniformly at the same distance of 30 meters each others and in a distribution of two per greenhouse within 3 greenhouses. The total length of the test was approximately 2 hours.

Figure 4a shows a measurement node with its protective casing designed to withstand the high temperature conditions inside the greenhouses.

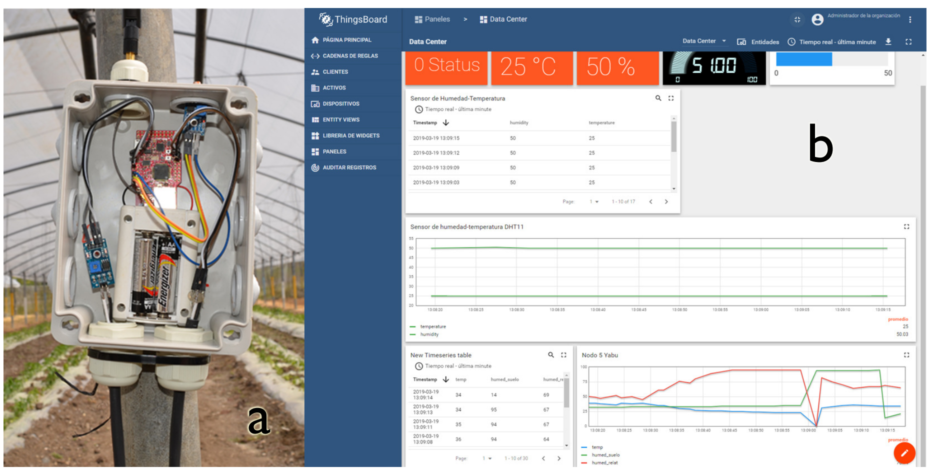

Fig. 4. Actual Implementation. a) Measurement Node with protective casing. b) ThingsBoard cluster dashboard showing information about node 5.

By the other hand, in Fig. 4b is depicted the developed ThingsBoard cluster dashboard with the information of temperature and relative humidity for the measurement node 5. This evidences that the proposed architecture is functional and allows to connect actual field devices from the cloud using MQTT protocol.

5 Conclusion and Remarks

In this research we proposed an IoT architecture for monitoring the greenhouses environmental parameters of luminous intensity, air temperature, relative humidity and soil moisture. The developed IoT gateway performs basic data preprocessing and data persistence, allowing more flexibility in the availability conditions of the Internet connection with the cloud. This also could be useful in

larger multi network scenario, when the IoT gateways could relieve from some basic processing task to the cloud services, giving this particular proposal, Fog Coputing paradigm capabilities. The use of TSCH based Orchestra and RPL allows to build a coherent multi-hop Wireless Sensor Network for the environmental parameter acquisition inside the greenhouses.

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