Smart UTB: An IoT platform for Smart Campus

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Abstract. The Internet of Things (IoT) aims to create applications to improve people's quality of life using novel protocols, sensor networks, cloud computing, middlewares and other technologies. These applications can be used in several contexts such as industry, agriculture or smart cities. On university campuses, applications based on IoT can also be implemented. The applications can be focused on monitoring people's behavior, smart buildings, or sustainable environments. Generally, IoT applications are not designed and developed in a standardized way. Besides that, university campuses do not have a platform to manage and deploy these applications easily. This work presents Smart UTB, an IoT platform designed by using the Industrial Internet Reference Architecture (IIRA) and focused in the management and deployment of IoT applications towards sustainability in a smart campus.

Keywords: Internet of Things · Smart Campus · Reference Architecture · Environmental Sustainability · Sustainability in Higher Education

1 Introduction

As we are living through the fourth industrial revolution, focusing mainly on the use and development of the Internet of Things (IoT), we are discovering the great advantages that it can give us in several fields and situations. One of these fields is environmental monitoring. Environmental monitoring gives key tools to those university campuses that point to sustainability within their institutional policies. Starting from the commitments and progress made by Higher Education Institutions (HEI) in the Stockholm Declaration [28], Talloires Declaration [25] and other declarations signed by universities around the world since the late 19th century [22], pointing to the incorporation of sustainability principles both in education, research and the physical space itself.

The Universidad Tecnológica de Bolívar (UTB), specifically, in order to strengthen its commitment to environmental sustainability, joins the UI GreenMetric World University Ranking in 2019, an initiative of the Universitas Indonesia with around 779 participants and ranking 486 [27].

The main objective of this work is to implement IoT solutions to the UTB campus in order to get the most of its capabilities, such as environmental monitoring. The article proposes a platform open to members of the University (Students and faculty members), so they are able to monitor environmental variables or add more sensors to the network for their own projects. Thus, this platform is a key tool for achieving the strengthening of the UTB as a sustainable campus, which offers its community a safe space consistent with the education provided and an accurate timely decision making process.

The paper is organized as follows: Section 2 discusses research in the field and their approaches. Section 3 shows the selected architecture for this work. Section 4 presents the implementation of the platform. Finally, Section 5 describes the conclusions of this work.

2 Related Work

The term Internet of Things (IoT) was coined by the work done by the MIT Auto-ID Center in 1999. In that work, an infrastructure was designed based on RFID [12]. However, just in the last few years this term has been popularized in several contexts. IoT allows users to interconnect heterogeneous physical devices gathering data to create many applications and services.

From a technical point of view, IoT is a paradigm that needs the integration of several technologies to be used: Machine to machine (M2M), cloud computing, big data, communication protocols and wireless sensor networks (WSN). Zhou et. al [31] presents a set of features and requirements to integrate those technologies:

- Data management: The "things" (devices) generate a huge quantity of data that need to be stored and managed.
- Web based interfaces: The "things" (devices) require this to exchange information and to integrate different applications.
- Interoperability: The "things" are heterogeneous. However, they must communicate between all devices.
- Real time: IoT applications can be classified into real time and no real time.
- Dynamic network: IoT will integrate several heterogeneous devices. The devices can be connected or disconnected at any moment.
- Everything as a service (XaaS): If the number of connected devices grows, then the number of applications will grow too. These services must be available to be used and reused.
- Security: IoT needs global accessibility and connectivity, which means anybody can access it in any moment and from any place. This increases the range of attacks for the IoT applications and networks.
- Privacy: Any IoT application must respect users' privacy.

IoT communication technologies enable the connection of heterogeneous devices and the creation of specific services. The tool that allows that communication is called protocol. Different protocols can be used in IoT applications according to several standards. Al-Fuqaha et. al [2] shows a list of the most relevant protocols, here we show some of them:

- HyperText Transfer Protocol (HTTP): This is the protocol that transfers most of the information used on the Internet. One of the development architectures based on this protocol is REST (REpresentational State Transfer). REST allows exchanging data between different clients and servers on HTTP in an easy way. REST enables the implementation of a non-state architecture. In other words, an action on a resource does not depend on another action.
- Constrained Application Protocol (CoAP): CoAP defines a web transfer protocol based on REST to implement HTTP functionalities. However, CoAP uses UDP (not TCP) by default, which is important to modify IoT applications. Additionally, CoAP modifies some functionalities of HTTP to achieve the IoT requirements such as low energy consumption and operations in presence of noisy links.
- Message Queue Telemetry Transport (MQTT): MQTT is a message protocol that was introduced by Andy Stanford-Clark from IBM and Arlen Nipper from Arcom (now EUROTECH) in 1999. MQTT aims to connect embedded devices and networks with applications and middlewares. The connection operation uses a routing mechanism and one-to-one, one-to-many and many-to-many. MQTT consists of three basic components: Subscriber, publisher and broker. A device can be registered as a subscriber for specific topics in order to be informed by the broker when the publishers publish on a topic. The publisher acts as the generator of the information. Then, the publisher transmits the information to the stakeholders (subscribers) through the broker.

The potentialities offered by IoT allow to develop a big number of applications. These applications can improve people's quality of life and can be deployed in different contexts: Health, agriculture, transport, sustainability and others. In the next subsection, we talk about the Internet of Things in sustainable applications, specifically for smart campuses.

2.1 Sustainability and IoT

Since 1962, when Rachel Carson published her book "Silent Spring" [3], talking about the concern around pesticides negative environmental effects on ecosystems and human health, it has become increasingly important to talk about the impacts from anthropogenic activities in both rural and urban areas, their ecosystems and population itself, as well as efforts to achieve a healthy environment.

Besides, during the United Nations Conference on the Human Environment, in 1972 [28], Higher Education Institutions were encouraged to incorporate educational programs into their curriculum that would generate knowledge around the problems of economic and population growth and environmental crisis. With the aim of achieving society awareness and strong environmental policies, based on the efforts from universities and the education system in general [7].

It was not until 1987 that a concept emerged and that would become important to understand the need to take action on all those impacts that Carson [3], Meadows et al. [13], and many other authors, society sectors, agendas, and statements [19] [21][4][10]; have demonstrated, debated and questioned. Considering the consequences of an economic and population growth that must consider its environment and importance for a society that depends on it for its survival. This concept is sustainable development, which is the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [16].

Added to the efforts made by these authors and Agendas, Stockholm Declaration [28], the Millennium Development Goals [17], current Sustainable Development Goals and its 2030 Agenda [18], have been focused on the achievement of sustainable development worldwide, but also in strengthen Sustainability in Higher Education (SHE), specifically.In recent decades, a series of sustainability rankings have been born [22] [14] [30] [9], evaluating aspects such as environmental management policies themselves, education in sustainability and research carried out by the Higher Education Institutions (HEI). Among these rankings is the UI GreenMetric World University Ranking, which is an initiative launched in 2010 by the Universitas Indonesia to recognize those universities that were making efforts to reduce environmental impact and combat climate change, and establish a uniform and attractive system where universities could numerically measure their progress and compare themselves with other committed universities worldwide [27].

Several works related to sustainability have been developed in the last few years. Xiaojun et. al [29] noted that doing an empirical analysis of air pollution with an automatic monitoring system with high precision and forecasting features is too expensive, so they present an IoT system that reduces the hardware cost to 1/10 and the information collected allows use of a neural network to the forecasting task.

Ahmed et. al [1] show WaterGrid-Sense as a node based on LoRa to monitor and control a smart water management system. It is a full stack node with all the components integrated in a single board. Besides, they conducted two experiments with good results related to power consumption and communication reliability.

If we talk about smart campuses applications, Marchetti et. al [11] present an initiative to create a sustainable campus where low cost technologies are used for monitoring environmental parameters such as carbon dioxide, humidity and temperature in the classrooms of the University of Ferrara. Other systems have been developed in order to monitor ultra-fine particles (PM2.5) in the campus using LoRaWAN [20]. This is done with the objective of testing the quality of the air which can affect people in the campus. Rodrigues [23] uses LoRaWAN also, several devices were distributed inside a university campus to monitor harmful gas emissions to people's health and generate alerts for the academic community and the campus administration to improve the quality of campus' environment.

MQTT protocol has also been used for these applications, Muladi [15] shows a system to monitor air quality in a campus using MQTT. To develop that system, a wireless sensor network was created using Arduino and Raspberry Pi and the collected information is visualized using a web application.

We have seen that these applications have been implemented in a variety of platforms, using various protocols to offer some kind of information to the users. In our approach, we created a platform that could allow students at the University to create their own application towards sustainability. Giving more flexibility when it comes to the use of sensors and the way each user receives the information. Also, by making the programming part easier, students can focus on work on a useful application for the campus.

3 Architecture

To be able to implement our proposed solution, first we need to design an architecture that can manage all the users, teams and IoT applications that we want to deploy. In this section we describe the proposed architecture for the development of the platform.

Reference architectures have been developed to establish a set of rules to develop IoT systems in a standardized way. IIRA (Industrial Internet Reference Architecture) is a reference based on functional aspects of IoT applied to industry [8]. IIRA identifies common architectural issues on IoT systems and classifies the issues on viewpoints with the stakeholders. This reference architecture defines four viewpoints: Business, Use, Functional and Implementation.

Business and Use viewpoints are focused on the stakeholders and the description of activities on several system's components. On the other hand, Functional and Implementation viewpoints are related with the requirements, features and design of typical IoT systems. IIRA presents an architectural pattern of three tiers which show the details of the required components and technologies to develop an IoT System. This pattern mixes most of the components from functional domains and is made up of an Edge Tier, a Platform Tier, and an Enterprise Tier.

On the Edge Tier, the control domain is implemented. The control domain represents a set of functions with sensors and actuators. Basically, several devices collect data in this tier. On Platform Tier the information and operation domains are implemented. This tier is related to data management and storage, and with this information, the system tasks can be optimized. Finally, Enterprise Tier implements applications of specific domains, supports system decisions and provides user interfaces.

This work presents an architecture based on the three-tier architectural pattern of IIRA. Fig. 1 shows the details of the architecture, and its components are described in the next paragraph.

On the Edge Tier, several devices are sensing data and actuators can be activated according to the system's rules. Besides, the devices can be connected to the platform using IoT protocols through the APIs. The data is processed and

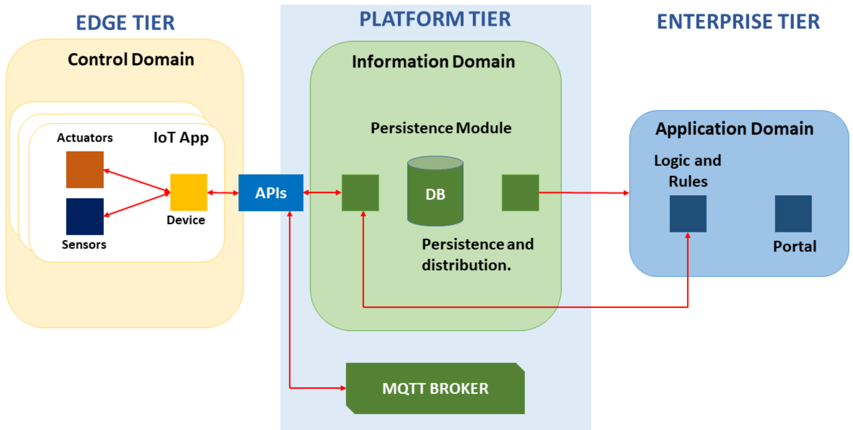

Fig. 1. Designed architecture for the system based on [8]

analyzed on the information domain, pipelines can be used to improve real-time data processing. The information analysis is sent to the operation domain. After that, the operation domain makes decisions according to the rules established by the stakeholders, then it sends the decision to the control domain. On the Enterprise tier, a customized dashboard shows relevant information to the final user and provides a set of tools to create the system's rules. Those rules are used by the operation domain to make decisions.

The proposed platform was designed in a standardized way, this allows to add more features and services in the future. Also, the use of IIRA in this work can be used as a guide for other IoT developers.

4 Implementation

In order to implement the platform according to the architecture described before, we selected ThingsBoard [26] version 3.1.0. Thingsboard is an open source framework to develop IoT platforms. This framework was chosen given that it has all the system modules needed for the proposed architecture. It provides a set of tools for device creation, user management, rules definition and application management. Moreover, this framework offers support to several IoT protocols such as HTTP, MQTT, Sigfox or CoAP, giving the possibility to scale this platform to these communication protocols. Thingsboard also allows the users to define rules through what they call "nodes". The users can create alarms, send emails when it is triggered, and other functionalities that make it easier for students to create their own smart campus application.

On the other hand, an IoT indoor air application was developed to validate the use of the platform. The application aims to monitor the quality of the air but also to generate alarms in case it is required. The variables to be sensed are CO2, temperature and humidity, which are commonly used for this task [24][15][11]. Next, it was necessary to select the right hardware for this app. The app includes two NodeMCU (a development card based on ESP8266 processor), two sensors MQ135 to measure CO2 and two sensors DHT11 to measure humidity and temperature. Also, it is important to say that the devices are located in different locations, which is one of the great features that IoT offers.

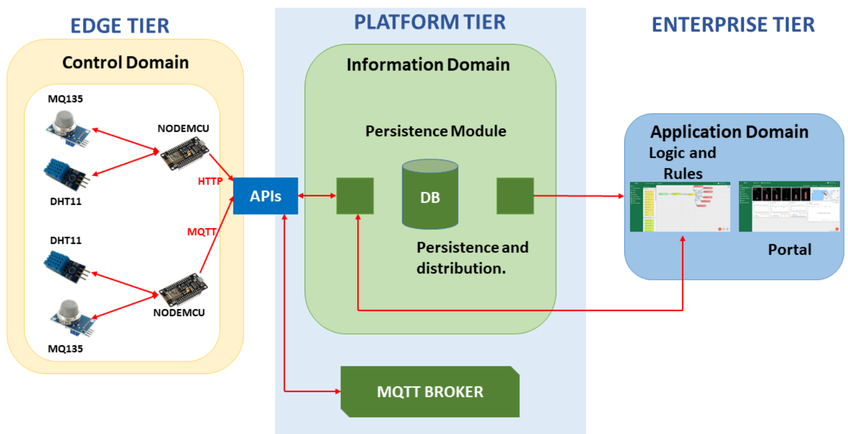

Fig. 2. Proposed IoT indoor application.

Fig. 2 shows the architecture of the proposed app. Each NodeMCU has a MQ135 and a DHT11 connected. One of them sends the data to the platform using a HTTP API, and the other one sends the data using a MQTT API. The use of different protocols aims to demonstrate the interoperability of the platform. The information is processed and then shown in a customizable dashboard (See Fig. 3).

The platform provides a tool to set several alarms, depending on the application. In this case, six alarms were created in order to test this feature. Fig. 4 presents how the alarms were configured using a visual tool, if the measured values are greater than a threshold, then the alarm is activated. This visual tool allows a user with little knowledge on programming to configure the alarms by themselves. Although this is a simple example, more advanced alarms can be configured with some coding on the tool. Finally, the alarm that was generated can be seen from the dashboard and that an email was sent to the stakeholders (Fig. 5). In this test, the alarms were configured to be triggered when the CO_2 and humidity values were higher than a certain threshold (in this case it was below the reference values established by current regulations [5][6], so we could test the alarm functionality).

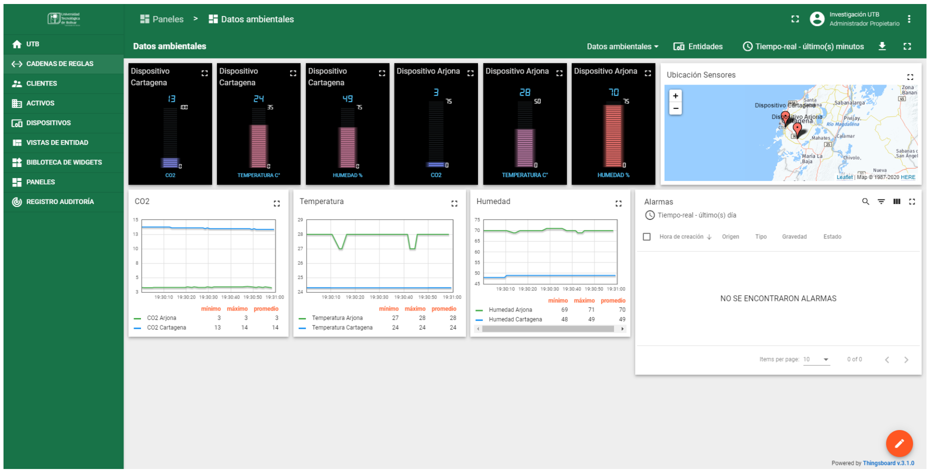

Fig. 3. Dashboard of the application.

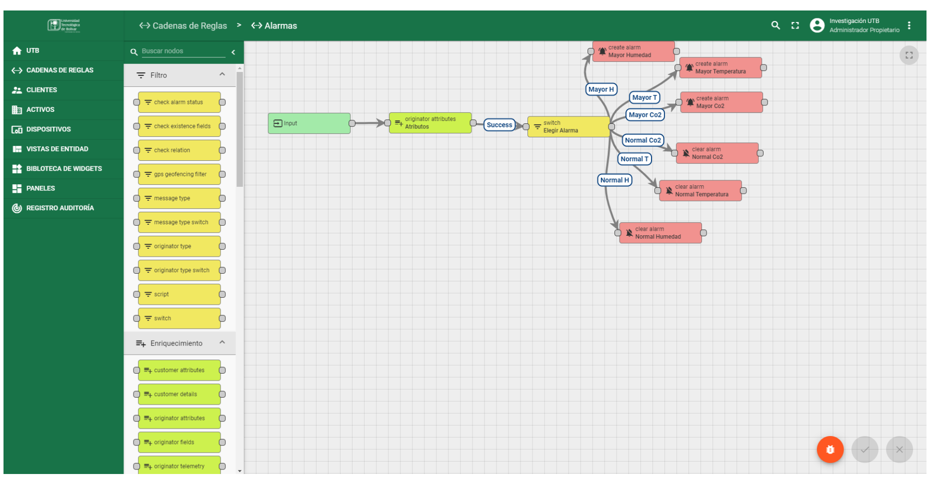

Fig. 4. Set of alarms for the IoT application.

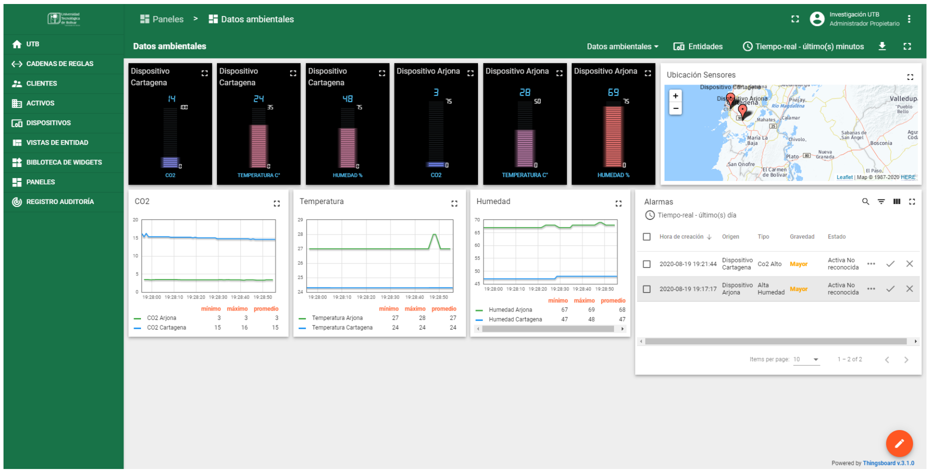

Fig. 5. Dashboard with the activated alarms.

The proposed platform was developed following a reference architecture, which allows additional features to be easily added later. Additionally, the platform offers an inter-operable environment, because devices can communicate using different protocols such as MQTT or HTTP. Finally, several applications can be developed in this way and may be integrated to the platform using the available APIs, in order to provide the student community information about the campus and make decisions to improve it.

5 Conclusions

The Internet of Things is a novel paradigm that allows to create applications which aim to improve the people's quality of life. These applications can be deployed on several fields such as health, industry, agriculture, and others. This work is focused on the concept of a smart campus, where several IoT applications can gather data and give relevant information about some conditions of the campus. In general, applications on IoT need the integration of several technologies, devices, protocols and web applications. This forces the developer to have knowledge and duplicate his efforts in building the mechanisms to allow the integration, neglecting the main task of developing the application.

This work presents Smart UTB, a platform for the deployment and management of Internet of Things applications on a smart campus. This platform was designed and developed in a standardized way, specifically using the guidelines described on IIRA. The platform enables users to create work groups to manage their own IoT application, this is ideal in a university environment where we can find several academic groups.

The applications that can be managed in the platform can be focused on several fields, the only requirement is that the protocol must use the devices. In order to offer an inter-operable platform, two APIs are available, one for the HTTP and another for the MQTT protocol. On the other hand, the developers of the application can set alarms from the platform if it's necessary.

To validate the use of the platform, an IoT indoor air application was developed. The devices use both protocols supported by the platform to demonstrate the interoperability. Several alarms were configured also.

The design and the development of the platform and the IoT app presented in this work can be used for the IoT community to build applications using reference architectures. Besides, the smart campus platform can be used by the student community to deploy applications or test the concept of IoT. As future work, we propose to add support to other IoT protocols such as LoRA, CoAP and Sigfox. Additionally, it would be important to test the scalability of the solution and add some analytic features to improve campus decision-making process.

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