4

Real-time Management of Energy Consumption in Water Resource Recovery Facilities Using IoT Technologies

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Abstract

The real-time management of energy consumption in Water Resource Recovery Facilities is key for the intended implementation of demand-side management in those Facilities, with the objective of optimizing energy consumption. For this objective, special purpose energy meters have been designed, implemented and deployed. The energy meters measure several electrical parameters for the distinct processes and equipment in the Water Resource Recovery Facilities, transmitting those measurements to a central platform where they are stored and treated. The communication architecture chosen for this purpose is based on the Internet of Things paradigm, using Wi-Fi or LoRa protocols for communication within the Facilities, a private network for external access to the water company servers and MQTT as the higher layer protocol for data transfer. At the moment, thirty-seven energy meters are deployed in two Water Resource Recovery Facilities in Lisbon, Portugal, and some of the measurement results obtained are shown in the article.

4.1 Introduction

Águas do Tejo Atlântico (AdTA) is a leading company operating in the environmental sector in Portugal, and its mission is to contribute to the pursuit of national objectives in the wastewater collection and treatment within a framework of economic, financial, technical, social and environmental sustainability.

AdTA has the responsibility to manage and operate the wastewater multi-municipality system of the Great Lisbon and West of Great Lisbon areas, guaranteeing the quality, continuity and efficiency of the water public services, in order to protect the public health, population welfare, the accessibility to the public services, the environmental protection and economic and financial sustainability of the sector, in a framework of equity and tariff stability, contributing also to the regional development and planning.

AdTA manages 103 Water Resource Recovery Facilities (WRRF), 268 pumping stations and 1093.40 km of main sewage system, and treats around 194 $\mathrm{Mm}^3/\mathrm{year}$, serving a population of 2.4 million inhabitants and a covered area of 4,145 km^2.

A WRRF refers to a facility designed to treat municipal wastewater and recover sub-products, such as bio-solids, treated wastewater and energy. The level of treatment at a plant will vary based on the water bodies classification and the specific processes involved. Treatment processes may include biological, chemical, and physical treatment.

Energy is often the second highest operating cost at a WRRF after the labor cost; it can be about 50% of a utility's total operating costs [1]. The reason for this is that most of the processes that occur in a WRRF require energy for their operation and are intensive energy consumers, such as aeration and elevation. In 2018, the energy consumption at AdTA was about 92,206,887 kWh and represented 49% (€ 8,378,240) of the operating costs.

In the WRRF, the most significant energy consumption is related with biological treatment (aeration) and pumping. However, it is expected to have an increase of energy consumption in the wastewater industry due to: more demanding legal discharge limits that in some cases may imply the use of energy intensive technologies; sludge advanced treatment such as drying, incineration and pyrolysis; and natural ageing of sewage systems resulting in increase of infiltrations, with the consequent pumping and transportation costs [2].

Nowadays, also new challenges appear due to the limited water and nutrient resources, to the existence of the circular economy framework, and to climate changes concerns associated with the fossil fuel consumption. In this context, a new paradigm for the use of the domestic wastewater was created where domestic wastewater is being looked more as a resource than a waste and the wastewater treatment plants now are known as WRRF, where it is possible to recover nutrients and water to achieve a more sustainable use of the wastewater energy potential, and become a driver for the circular economy [3].

AdTA is a consortium member of the running European Union H2020 research project “Intelligent Grid Technologies for Renewables Integration and Interactive Consumer Participation Enabling Interoperable Market Solutions and Interconnected Stakeholders”, which has the acronym InteGrid. The main objectives of InteGrid are to test the flexibility of electrical energy consumption for domestic and industrial consumers, to test energy storage systems and to make forecasts of renewable energy production and consumption. The main role of AdTA in this project is to manage the flexibility of its internal processes in order to minimize the energy costs according to the market and to the requirements of the electrical grid operators, leading to an optimization of the AdTA internal processes, through a demand side management paradigm.

The AdTA role focusses into the flexibility of energy consumption and into the new challenges of turning a wastewater treatment plant into a WRRF. This is an important path towards its objective of achieving operational optimization and flexibility of processes. To optimize and make processes more flexible it is essential to know the performance of the processes. Thus, one of the variables to monitor is the energy consumption of the different processes and equipment. This article is related with the specific work done for real-time monitoring of the electrical energy consumption in WRRF by using Internet of Things (IoT) technologies. This work is being done by AdTA, within the InteGrid project, in collaboration with INOV, a Portuguese research institute.

The use of IoT technologies, at the communication and platform levels, means a state-of-the-art solution for the management of energy consumption in WRRF, which may become an important vertical domain in the vast area of IoT applications.

A first article has already described the basic ideas of the project and the plans for its implementation [4]. The present article, besides introducing the main architectural concepts, has a strong focus into the deployment done and some of the obtained results. Section 2 reports on the related work. Section 3 is dedicated to the IoT based communication architecture adopted in the project and Section 4 deals with the implementation of the energy meter. Sections 5 and 6 describe the deployment and the obtained results, respectively. We conclude in Section 7.

4.2 Related Work

Currently, more than optimizing energy generation and distribution, it is the demand side management that is receiving increasing attention by research and industry [5]. Energy systems are sensitive to energy consumption spikes and, therefore, measurements have to be taken, either to optimize energy generation and distribution or to reduce and shift peak power demands.

Energy operating costs significantly depend on the energy tariff structure applied, but in most energy studies, the energy consumption is multiplied by an average energy price. Different time-of-use and/or peak penalty charges may change the cost efficiency of a control solution completely [6]. There still exists a gap between energy consumption and costs since there is no generalized cost model describing current energy tariff structures to evaluate operating costs at WRRF [7].

An application of a real energy pricing structure was applied to a calibrated model for evaluating operational strategies in two large WRRF, in the context of the Portuguese “SmartWater4Energy” project [8]. The importance and need of mathematical modelling for energy optimization of specific energy costs at real WRRF processes was assessed. Time periods with potential for further optimization were identified, supporting a smart grid basis in terms of water and energy markets that respond to the demands. This work was developed in the AQUASAFE platform [9, 10], where the different models and the data from different sensors were included for calibrating and evaluating the models. However, most of the energy consumption measurements in the scope of this project are done in an indirect way, through the Supervisory Control and Data Acquisition (SCADA) system of AdTA. The AQUASAFE platform is a structure that allows managing information from different sources (e.g., SCADA systems, SQL, FTP servers) necessary to obtain an adequate response in the context of the management. The AQUASAFE platform was developed at AdTA, integrating data already existing in the company, in order to produce answers to the specific needs of the operation and management (e.g., overflows, energy management, emergency response). The measured data, mainly from water flows, is imported in real-time and the models run periodically in the forecast mode in simulation scenarios chosen by the user. The AQUASAFE platform is in use at AdTA nowadays.

Thus, access to real-time total energy consumption of WRRF is important, but there is also a need to have accurate measurements on the energy consumption and other electrical parameters in real-time for the WRRF and their equipment/processes. This is done having in view the objective of checking and monitoring the implementation of efficiency/optimization measures and the flexibility of electrical energy consumption at a WRRF, since it is not always possible to evaluate the effectiveness of the measures implemented by accessing only the total energy consumption of a WRRF. Those detailed measurements need to be communicated to the AQUASAFE platform, which has analytical capability to extract information from the data being measured and then it will be possible to design a strategy for shifting peak loads and reducing energy consumption. These are the main reasons that originated the developments described in this article.

On what concerns the development of dedicated energy meters to measure several electrical parameters like current, voltage and power in real-time, and adapted for wireless sensor network communications, there is previous work already done for the smart grid environment [11, 12]. In the present case, the energy meters will be different from those ones as, now, they must have the following distinctive characteristics: (i) to be adapted to the constraints of a WRRF deployment; (ii) to measure the parameters required in WRRF environment; (iii) to comply with the IoT communications paradigm and platform architecture; (iv) to be low cost, as a large number of meters is required to cover the universe of WRRF.

4.3 Communication Architecture

The IoT based communication architecture adopted for this case considers each meter and the respective equipment to which is connected as a "thing". The data generated from all the things is stored in the database of a central AdTA server. The communication between the things and the server is done through the private AdTA wide area network for security reasons.

From the universe of the IoT communication protocols [13], we have considered that Wi-Fi [14] and LoRa [15] would be two appropriate standard communication technologies to employ in this use case.

Wi-Fi is a well-known technology, having low cost communication modules for the meters, a low-cost Access Point (AP), and high data rates (Mbps). As low cost is a key objective, the choice of Wi-Fi as one of the selected technologies looked appropriate.

LoRa was the second technology selected for the use case. LoRa is the physical layer containing the wireless modulation utilized to create a long-range communication link. The complete stack of protocols used over LoRa is known as LoRaWAN (LoRa Wide Area Network). Compared to Wi-Fi, LoRa has lower data rates (Kbps) and the cost of the LoRa gateway is higher than the Wi-Fi AP. However, its installation might be simpler than Wi-Fi in more complex networks and it enables a longer communication distance than Wi-Fi, which is very useful for the communication between some remote equipment in the WRRF and the LoRa gateway.

The decision taken for the InteGrid pilots was to test Wi-Fi in one WRRF (located at Chelas) and LoRa in another WRRF (located at Beirolas), both in the Lisbon urban area. As it is required to transmit the data from the energy meters to the Control Centre, we had to establish a communication architecture that would allow a seamless and secure transmission. The chosen architecture is shown in Figure 4.1, both for the Wi-Fi and the LoRa access cases.

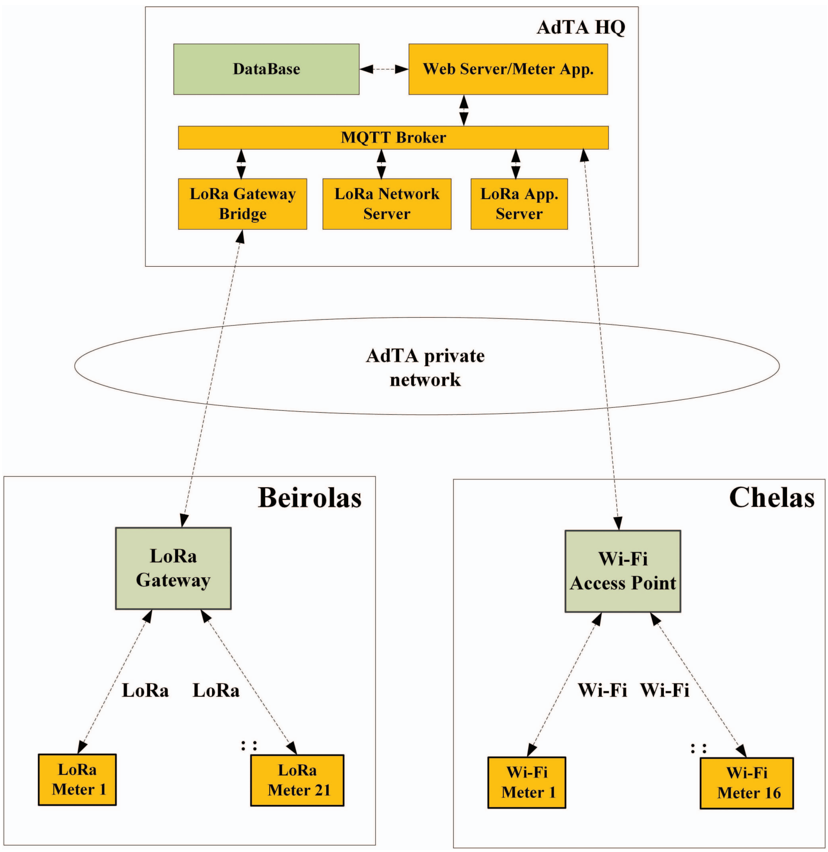

Figure 4.1 Wi-Fi and LoRa based communication architecture.

There might be several Wi-Fi APs installed in a WRRF. The WRRF energy meters are deployed in different WRRF equipment, e.g., recirculating pumps, equalization pumps, ventilators, etc. The meters communicate to the nearest Wi-Fi AP, sending a message containing the meter identification, followed by the electrical measurements. The data is forwarded from the Wi-Fi AP to an AdTA Server located at the Control Centre of AdTA Headquarters (HQ) via the AdTA private communication network. The data is uploaded into the database via Java Script Object Notation (JSON) format commands. The users can access the data either via a direct connection to the database or indirectly through a Web server.

Figure 4.2 shows a simplified protocol stack of the Wi-Fi based access network. A conventional TCP/IP stack of protocols is used over the Wi-Fi Medium Access Control (MAC) and Physical (PHY) layers. The Wi-Fi AP converts Wi-Fi into Ethernet and communicates with the AdTA server via the AdTA private wide area network.

For the communication system with LoRa at the physical layer, the communication architecture is similar to the one indicated for the Wi-Fi case, having as a main difference the use of a Gateway instead of the Wi-Fi AP.

Figure 4.3 shows the protocol stack of LoRaWAN, which comprises four layers: Radio Frequency layer, Physical layer, Media Access Control (MAC) layer and Application layer.

The Radio Frequency layer defines the radio frequency bands that can be used in LoRa. We adopted the 868 MHz band available for Industry, Scientific and Medical (ISM) applications in Europe. The LoRa physical layer implements a derivative of the Chirp Spread Spectrum (CSS) scheme. CSS aims to offer the same efficiency in range, resolution and speed of acquisition, but without the high peak power of the traditional short pulse mechanism. The MAC layer defines three classes of end nodes, respectively Class A (baseline), B (beacon) and C (continuous). In this project we use

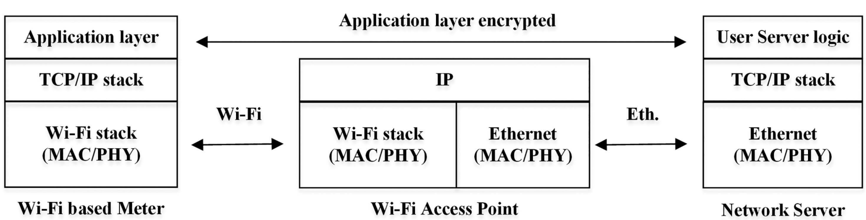

Figure 4.2 Protocol stack of the Wi-Fi access network.

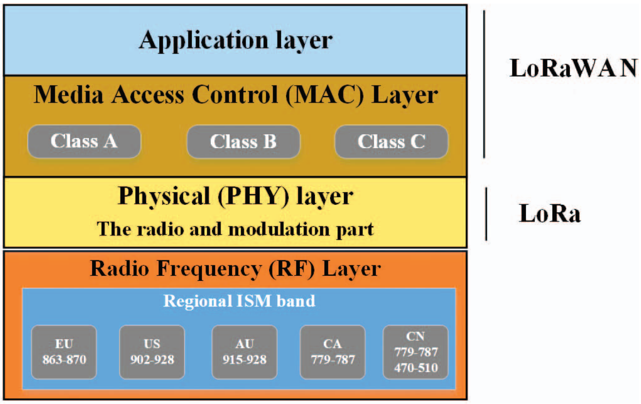

Figure 4.3 LoRaWAN communication layers.

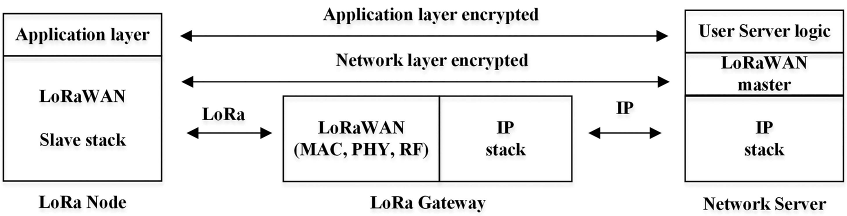

Figure 4.4 Protocol stack of the LoRa access network.

only Class A, since it is the most energy efficient and the only one that is mandatory. To achieve this high energy efficiency, the nodes in this class are 99% of the time inactive and are only ready to receive after transmitting a message. The Application layer is related with the user application.

The basic components of the LoRaWAN architecture are the following: nodes, gateways and network server. The nodes are the simplest elements of the LoRa network, where the sensing or control is undertaken. The gateway receives the data from the LoRa nodes and transfers them into the backhaul system. The gateways are connected to the network server using standard IP connections. On this way, the data communication uses a standard protocol, but any other communication network, either public or private, can be used. The LoRa network server manages the network, acting to eliminate duplicate packets, scheduling acknowledgements, and adapting data rates. Figure 4.4 shows a simplified protocol stack of the interconnected components.

The high-level communication between an energy meter and the AdTA server uses the Message Queuing Telemetry Transport (MQTT) protocol.

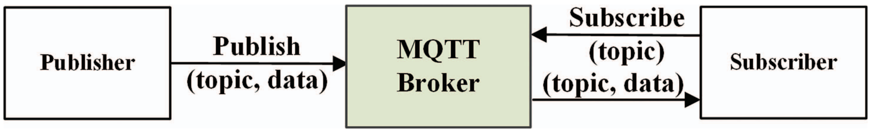

Figure 4.5 MQTT communication architecture.

MQTT is an IoT connectivity protocol. It was designed as a lightweight broker-based publish/subscribe messaging protocol, which is open, simple, lightweight and easy to implement. These characteristics make it ideal for use in constrained environments, for example, where the network has low bandwidth or is unreliable, as is the case of wireless sensor communications, or when run on an embedded device with limited processor or memory resources, as is the case of the energy meters.

In the MQTT architecture the elements that generate information are called Publishers and the elements that receive information are called Subscribers. The Publishers and Subscribers are interconnected through the MQTT broker, as shown in Figure 4.5.

The energy meter contains a MQTT client and the server a MQTT broker. Periodically, e.g., every minute, the meter sends a MQTT Publish message to the MQTT broker, located in the server, with the following structure: Meter ID, Voltage, Current, Power, Power Factor, Energy, Service Time, Timestamp. For configuration of the different parameters in the energy meter the MQTT broker uses Subscribe messages with different topics, namely: Change of the measurement period, Change of the communication parameters (specific of Wi-Fi or LoRa), Set date/time, Set the initial value of the energy counter, Set current transformer ratio, Set Power Threshold (define the power threshold to consider that the equipment is in service), Set Meter mode (tri-phasic or 3 x mono-phasic).

4.4 The Energy Meter

The energy meter was designed to allow the monitoring, not only from energy consumption, but also of other electrical parameters like current, voltage, power and power factor.

The energy meter is housed in a 6U DIN-rail ABS polymer enclosure ($69 \text{ mm} \times 87 \text{ mm} \times 66 \text{ mm}$) using 4 pins for the three voltage phases and neutral connection at the bottom (V1, V2, V3, N) and 6 pins for the connection of 3 current transformers at the top, one for each phase (I1+, I1−, I2+, I2−, I3+, I3−).

At the top there are two additional indicators, on the left side the L1 red led blinks when there is a message being transmitted. On the right side, the L2 green led blinks when there is energy consumption.

There are two versions of the energy meter, one with Wi-Fi communication and another with LoRa communication.

The energy meter block diagram is shown in Figure 4.6 and comprises four main modules: Measurement module, Processing & Communication module, Galvanic Isolation module and AC/DC dual power supply module.

The Measurement module and the Processing & Communication module are galvanic isolated for user protection, namely for the antenna connector and antenna cable handling. This requires a dual power supply with one of them connected to the Measurement module and the other to the Processing & Communication module. The Galvanic Isolation module is required to be connected to both.

The power, power factor, energy consumption and service time are calculated internally in the energy meter from the voltage and current readings. They are transmitted to the AdTA server, via MQTT protocol messages, using the following units for the different parameters: Voltage: 0.1 Volt, Current: 0.1 Ampere, Power: Watt, Power Factor: 0–100 (100 corresponds to Power

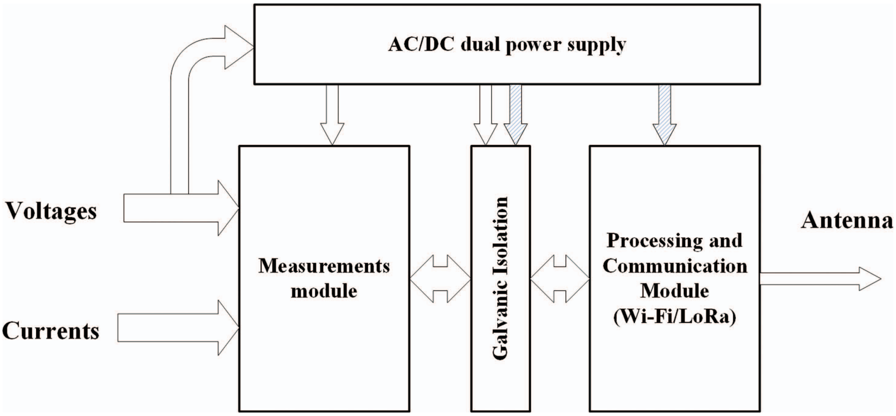

Figure 4.6 Energy meter block diagram.

Factor = 1), Energy: 0.1 kWh (accumulated value), Service Time: minutes (accumulated value), Time Stamp: seconds.

4.5 Deployment

The meters were deployed in two large WRRF in the Lisbon urban area, located at Chelas and Beirolas, respectively. Taking into account their relatively large size, these WRRF were considered as very suitable for the use case demonstrations.

In 2018, the Chelas subsystem (including WRRF and pumping stations on drainage system) treated 12,950,357 m^3 and consumed 6,488,170 kWh, which is about 6.7% of the treated wastewater and 7% of the energy consumption in the AdTA universe (6% of the energy costs). On the other hand, in 2018, the Beirolas subsystem (including WRRF and pumping stations on drainage system) treated 14,573,955 m^3 and consumed 6,703,237 kWh, which is about 7.5% of the treated wastewater and 7.3% of the energy consumption in the AdTA universe (8.3% of the energy costs).

In the AdTA universe, these two subsystems represent 14.3% of energy costs and also produce energy that is consumed in their internal processes. In Beirolas, 14.1% of energy consumption is from co-generation energy production and in Chelas, it is about 24.5%.

Sixteen energy meters with the Wi-Fi module were installed in Chelas, while twenty-one meters with the LoRa module were installed in Beirolas. The first objective was to test both communication technologies in order to make an evaluation of their strong and weak aspects, from the technical and economic points of view. The second objective is that AdTA is able to perform demand side management operations in both of them in the context of the InteGrid project. By having the knowledge on the real-time energy consumption and on the values of other electrical parameters, in a demand side management situation AdTA will be able to shift loads in a controlled way so that the impact is minimized in the WRRF.

The Chelas WRRF, shown in Figure 4.7, covers an area of around 37,500 m^2 ($250\ m \times 150\ m$) in a central area of Lisbon.

Figure 4.8 shows the plant of the Chelas WRRF, where Pi signals the points where the meters equipped with Wi-Fi are located and AP indicates the location of a Wi-Fi Access Point. The number of meters in each AP

Figure 4.7 Aerial view of the Chelas WRRF.

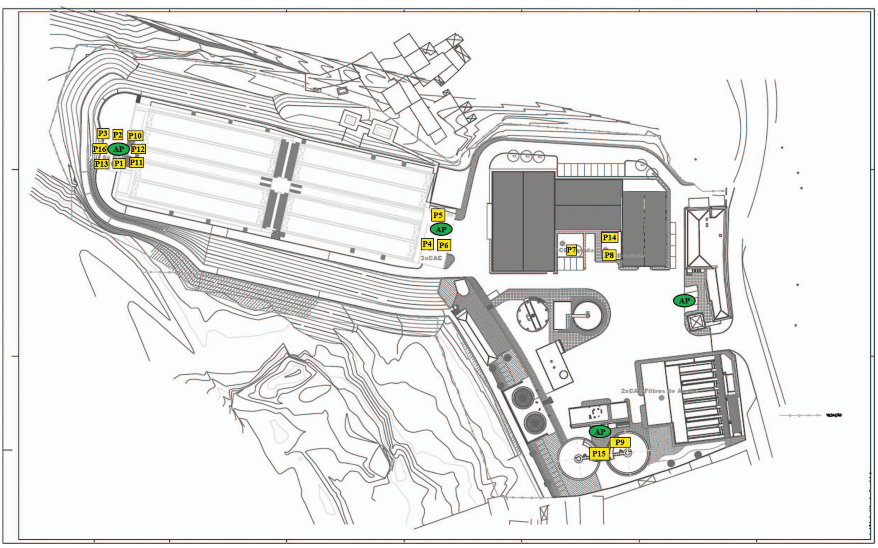

Figure 4.8 Wi-Fi based deployment at Chelas WRRF.

is variable, depending on the topology of the Wi-Fi network. The meters are connected to different WRRF equipment, such as pumps and ventilators. There are 4 Wi-Fi APs deployed to interact directly with the meters. However, due to the large area size and to the propagation characteristics in

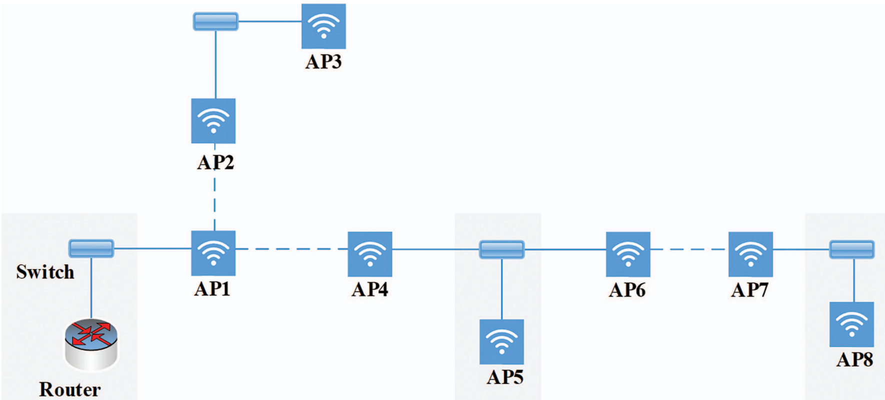

Figure 4.9 Wi-Fi network at the Chelas WRRF.

the WRRF environment (e.g., meters installed in metallic cupboards), four more additional APs were installed in a wireless mesh configuration. The deployed Wi-Fi network is shown in Figure 4.9.

As shown in Figure 4.9, the Wi-Fi network requires the deployment of three radio links, namely between AP1 - AP2, AP1 - AP4 and AP6 - AP7. To avoid interferences, these radio links operate in the 5 GHz ISM band, while the communication with the meters is done in the 2.4 GHz ISM band. AP1, AP3, AP5 and AP8 are the APs that directly contact with the meters.

The Beirolas WRRF, shown in Figure 4.10, covers a larger area of around 100,000 m^2 (400 m $\times$ 250 m) in Lisbon.

Figure 4.11 shows the plant of the Beirolas WRRF, where Pi are the locations where the LoRa meters are placed. G is the location of the LoRa gateway and antenna. As the range of the LoRa technology is higher than the Wi-Fi technology, only a single Gateway is needed to cover all the area of the Beirolas WRRF, with an external antenna located on the roof of the same building where is the gateway, on the left of the figure. The location of the LoRa antenna is not ideal (it should be located on a more central point of the WRRF), but it was deployed there to simplify the connection with the AdTA private network.

Figure 4.10 Aerial view of the Beirolas WRRF.

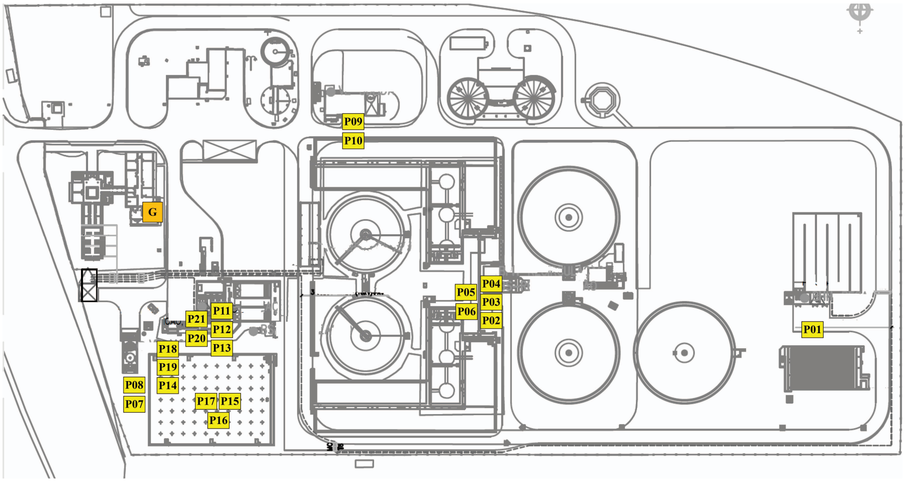

Figure 4.11 LoRa based deployment at Beirolas WRRF.

4.6 Measurement Results

To monitor the energy meters deployed in the different WRRF a web platform was developed, allowing to view the main electric parameters that have been measured.

As seen in Figure 4.12, the web platform screen shows on the left panel the meters that are online and on the right the different electrical parameters of the selected meter (MED19 in the example), namely the Service Time (T), Current (I), Voltage (V), Energy (E), Power (P) and Power Factor.

For each parameter, it is shown the value in each of the three phases (first three columns) and the average or total value in the fourth column. In this case, it is shown the average for service time, current, voltage and power factor, and the total value, resulting from the sum in the three phases, for energy and power.

The service time and energy are accumulated values, the others are instantaneous values captured when the message is sent, typically every minute.

Associated with each measurement, at the bottom of each box, we can see a timestamp showing the instant in which the measurement was made. This is especially important for the LoRa based meters where due to bandwidth limitations it is not possible to send all measurements in a single message.

In the database, only a subset of the electrical measurements is stored, namely the total power of the three phases, the total accumulated energy of the three phases and the service time, together with the meter id and time stamp.

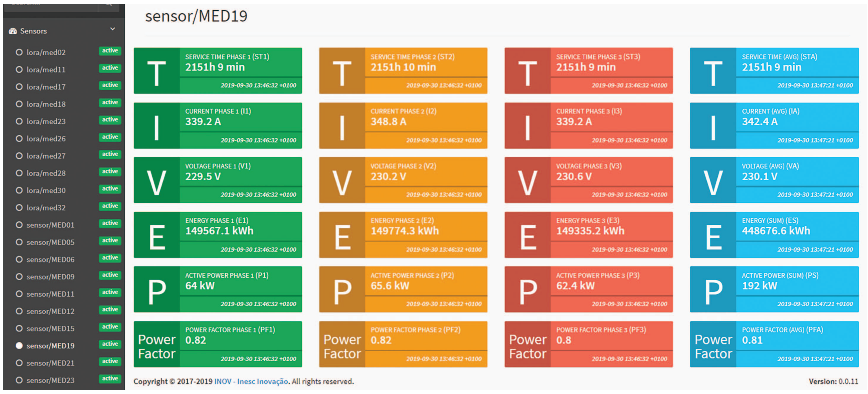

Figure 4.12 Monitoring web platform.

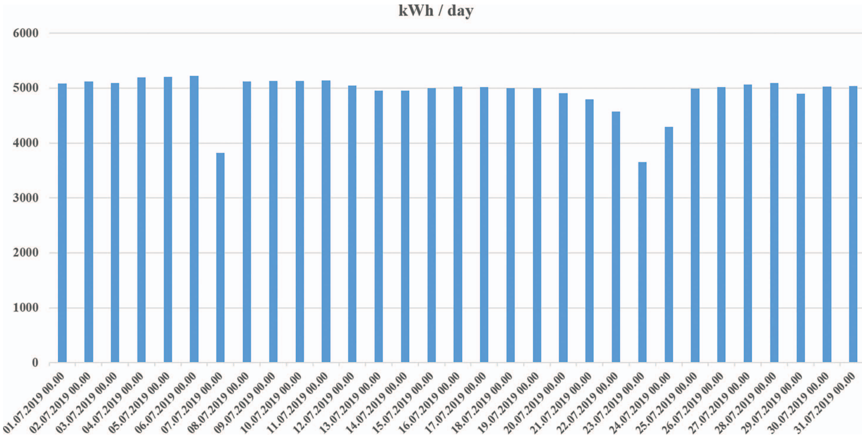

Figure 4.13 Consumption of meter 19 in July 2019.

Based on those values, we can create different graphics to show the consumption of the different meters. In Figure 4.13 we present an example of the consumption (in kWh) of the meter MED19 in July 2019.

In addition to the meter web platform, an application was also developed to configure the different meters, namely the measurement period, the energy threshold to activate the service time counter, the current transformer ratio, and the electrical parameters or internal registers that can be read on demand.

Besides the referred functionality, this application allows also to display, in graphical form, the relation between the voltage and current of the three phases, which is very useful in the meter installation, as it allows an easy detection of a wrong configuration and correct it on the spot. Figure 4.14 shows an example of this type of graphic. As seen in the figure, the voltages of the 3 phases are shifted by 120° as expected, and the currents are shifted around 32° to the right of the corresponding voltages, meaning that an inductive load is present.

Another interesting functionality of the developed application is to allow the calculation of the Discrete Fourier Transform of the voltage and current of a specific meter in order to calculate the respective harmonics. In the example presented in Figure 4.15, we can see a low harmonic content of both the voltage and current, still with significant higher values for the current.

At a next step, the data provided from the energy meters will be integrated in the AQUASAFE platform. The data is stored in the database of the AdTA server in real time as described and, automatically, the AQUASAFE imports all the energy meter information from the data files to the AQUASAFE

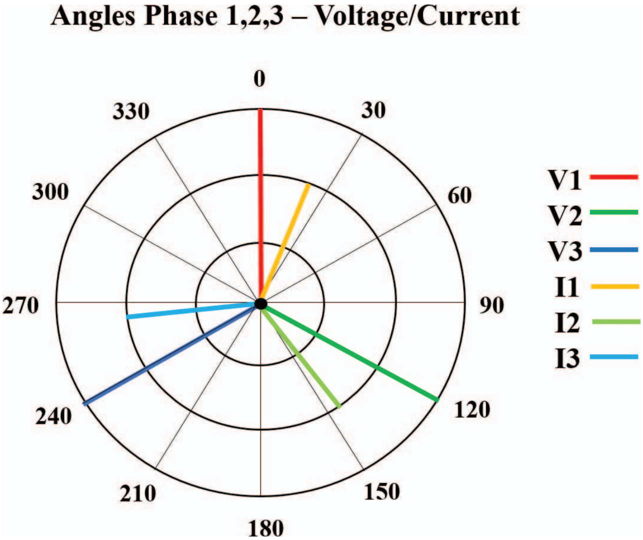

Figure 4.14 Polar Graphic of the voltage and current angles.

database recurring to an importer already installed in the AQUASAFE platform.

AdTA has also been working on the so-called flexibility matrixes and on their integration into the AQUASAFE platform. For the provision of the energy flexibility available in the WRRF, the solution developed in the InteGrid project is a Virtual Power Plant (VPP). A VPP is a cloud-based distributed power plant that aggregates the capacities of distributed energy resources for the purposes of enhancing power generation, as well as trading power on the electricity market. It was installed a File Transfer Protocol (FTP) server that connects the flexibility requests from the Distribution System Operator, the real time energy consumption of the WRRF and the WRRF available flexibility (flexibility matrix). Periodically, AQUASAFE will provide the positive and negative flexibility available in the WRRF to the VPP FTP Server. The FTP Server will then send an activation request with the flexibility demand needed and a Short Message Service (SMS) to the operator in the control room. The flexibility provision is activated manually by the operator, through the SCADA system, by turning on/off equipment or increasing/decreasing the power of the equipment according to the activation request.

Figure 4.15 Voltage and current harmonics.

4.7 Conclusion

An IoT based platform for real-time management of energy consumption in WRRF was presented. The developed work included the design and implementation of energy meters for measuring different electrical parameters, the deployment of those meters in two WRRF in the Lisbon urban area, the deployment of two IoT communication protocols (Wi-Fi and LoRa) for the access networks in the WRRF and the transmission of the data from either Wi-Fi APs or LoRa Gateway to a central server and database, via MQTT, where data analytics can be performed.

The objective of these two pilots was, in first place, to evaluate the chosen IoT communication technologies in the WRRF environment. The second objective was the enabling of demand side management operations, having in view the shifting of loads from peak load situations so that a better balance of the energy consumption can be achieved.

Concerning the evaluation of the Wi-Fi and LoRa technologies, both have proved satisfactorily for the WRRF environment, although due to the higher data rate, Wi-Fi allows having shorter intervals to make the measurements. On the other hand, the LoRa network is more straightforward to deploy in a WRRF than the Wi-Fi. For future deployments in other WRRF, any of those two protocols is technically adequate for real-time energy measurement and respective energy management operations, and the respective cost will be an important factor for decision.

From the web server where the data is stored and through a special purpose application developed, we are already able to perform some data analytics on the collected data. Examples were given of showing the energy consumption of a meter along a period of time, determination of a polar graphic of the voltage and current angles, and display of the current and voltage harmonics.

For future work, the implementation of the automatic data transfer to the AQUASAFE platform will permit integrating data analytics in that platform, which is already part of the working environment in AdTA. Also demand side management operations, based on the use of flexibility matrixes, will be shown for the WRRF in Chelas and Beirolas.

Finally, this work has also to do with the so-called smart wastewater management, which is an important component of the smart city concept. It is worthwhile noticing that by using IoT technologies, this solution is up to date with the status of communications and platforms in smart cities, which will enable the integration of this solution in a smart city environment.

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List of Abbreviations

AdTA	Águas do Tejo Atlântico
AP	Access Point
DIN	German Institute for Standardization
FTP	File Transfer Protocol
IoT	Internet of Things
IP	Internet Protocol
JSON	Java Script Object Notation
LoRa	Long Range
LoRaWAN	LoRa Wide Area Network
MAC	Media Access Control
MQTT	Message Queuing Telemetry Transport
PHY	Physical
SCADA	Supervisory Control and Data Acquisition
SMS	Short Message Service
TCP	Transmission Control Protocol
VPP	Virtual Power Plant
WRRF	Water Resource Recovery Facilities

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