Arduino-based IoT Capable Low Cost Smart Meter

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Abstract— **The objective of this work is to develop an electricity Smart Meter (SM) providing functionalities that allow for the remote monitoring and controlling of the bi-directional energy flow in the Low Voltage (LV) grid. The developed prototype can be deployed in a Photovoltaic (PV) micro-production installation, being able to cooperate with the Distribution System Operator (DSO) regarding remote readings and dynamic voltage control procedures, while keeping the prosumer informed about the active power, as well as odd or faulty situations (e.g., no production).**

To accomplish the result proposed with functionalities that are useful in the distributed energy grid, this project offers a device that is standard compliant by using DLMS, providing specific technical information to the DSO. Additionally, it has two low power wireless communication technologies: Bluetooth Low Energy (BLE), for short range local readings and configuration by the prosumer or maintenance teams; and Sigfox, a long range low power technology, which has a permanent cloud based storage and facilitates consultation of past and current records. The latter can be accessed by an Android application from a remote location.

Considering it is a low-cost device, a commercial version would be suitable, and could be readily integrated in the Smart Grid.

***Keywords*— Low Voltage Grid, Prosumer, Smart Grid, Smart Meter.**

I. Introduction

Many consumers have become prosumers, by taking a more active role in their household consumption and integrating ways of producing and storing energy. Combined with a powerful metering solution, that can control and monitor utilities, some benefits can be attained such as minimizing the owner's environmental footprint by increasing awareness of one's behavior.

SMs are becoming common smart devices present in residential buildings and industrial facilities. They have the important task of monitoring the consumption and micro-production of electricity, water and gas for a better control of the resources spent and produced, and for the detection of anomalies, equipment failure and emergency situations, issuing an alert regarding the problem at hand, so it can be promptly solved.

The primary objective of this project is the development of an energy metering device in an Arduino, that is capable of efficiently communicating using a set of technologies that allow for the improvement of the monitoring and control of the LV grid. Considering the objective of creating an electrical grid that is bi-directional with decentralized electric micro-generation, some adjustments to the current regulation mechanisms needs to be made, starting with the way the local metering and the monitoring in the Secondary Substations is realized. For this project, it is proposed the development of a SM with the following characteristics:

1. Capable of providing measurements of voltage, current and active power;
2. Implementation of the DLMS protocol that can be used for remote access using a Serial interface (eg.: via PLC modem);
3. BLE interface that can transmit measurements in regular intervals;
4. Sigfox interface that can transmit average measurements to be stored and later processed into visual data.

And also the development of an Android application with the following characteristics:

1. Capable of requesting and displaying the data provided by the BLE module;
2. Capable of requesting data to the Sigfox server and displaying it in a user-friendly way.

Figure 1 shows the communication technologies that will be used and the functionalities they will cover.

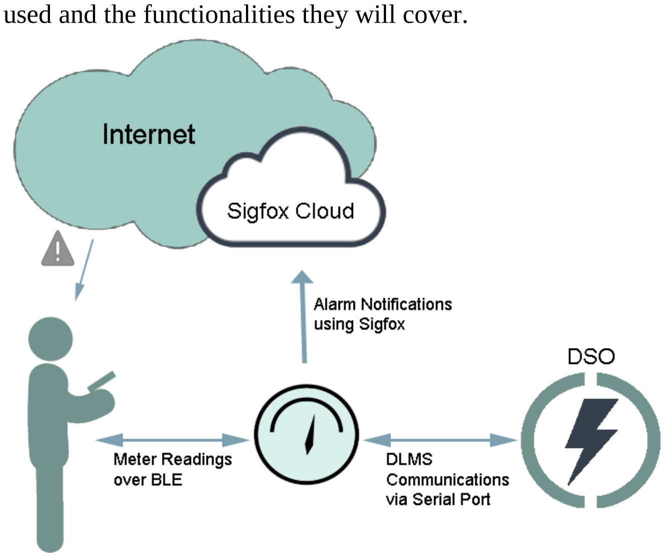


Figure 1 - Model of the System

II. Smart Grid

The electrical grid that presently exists has worked for a long time, but is not up to date with the modern technologies. We have been living with a grid that is composed of a one direction flow of electricity, where the population buys all the necessary resources for their daily activities, with little understanding of how taxing that is for our environment. Considering that now consumers can start producing energy in their households via renewable sources, powering said grid from the homes is now possible, promising the decrease of the use of fossil fuels and the reduction of electricity bills. That is one of the promises of the Smart Grid, the creation of a bi-directional power and data flow that is advantageous to the society [4].

With the arrival of the Smart Grid, Information and Communication Technologies (ICTs) start playing a major role, introducing concepts such as hourly tariffs and Time of Use (ToU), as well as dynamic pricing based on demand and supply conditions [5]. With the introduction of the ICTs in the Smart Grid, some problems were formulated regarding the homogeneity of the grid, since different utility networks require distinct functions and capabilities. This lead to the creation of conceptual models for certain communication networks, taking into account features such as scalability, bandwidth, range and service provided.

The analysis of information collected from each city, which includes domestic and industrial buildings, is really valuable considering the opportunities it creates. Taking advantage of the bi-directionality of the grid and the distributed energy production, exploiting statistics and prediction models based on consumer behaviours, it is possible to increase or decrease the power flow in certain areas of the city during peak or off-peak hours respectively, guaranteeing a more reliable and efficient grid, as well as minimizing waste, thus allowing providers to influence the grid stability.

All this is achievable if the used SMs are capable of gathering and transferring all the information pertinent to the correct management of the Smart Grid, without disregarding consumer's privacy and communication costs, both monetary and energetic. Also, these metering devices, with the correct infrastructures and extensions, should be autonomous enough to make decisions that can benefit users, managing and controlling certain areas of a residence and offering assistance in departments such as healthcare and surveillance [8].

A. *Wireless Technologies*

Wireless technologies connect heterogeneous objects for a complete integration of the services provided, offering the resources needed to platforms, so that data consumers can interact remotely with smart appliances. These protocols offer mobility and flexibility to those who use them, and are responsible for providing remote access to homeowners, utilities and third party service providers for a better incorporation of SMs in the Smart Grid. This chapter introduces some IoT communication protocols, both short range and long range, providing a description of their features and main functionalities.

1) *Bluetooth Low Energy (BLE)*

Developed by the Bluetooth Special Interest Group (SIG), BLE is a low power, wireless technology for short range communication [10]. This lower power feature was added in the Bluetooth 4.0 specification [11].

BLE defines several Radio Frequency (RF) channels, divided into advertisement and data channels. The former is used as a device announcement for the purpose of establishing connections, or to make broadcast transmissions, and the latter for bidirectional communication between paired devices that already share a connection.

Nowadays most gadgets are dual-mode devices, meaning they come with both the classical version of Bluetooth and the low power version as well. This happens due to the incompatibility of these types of controllers, since communications between a device that only implements BLE and other that only implements classic Bluetooth are not possible. But considering the fact that BLE is easily integrated into the classic Bluetooth circuitry, it guarantees that most devices that already use Bluetooth will continue to do so, keeping its strong position in the market, as is the case of smartphones [12].

When compared with its predecessor, BLE has a serious advantage when it come to power consumption though it comes at the cost of the range and data payload, though these can be adjusted to meet most application requirements. This low data payload results in the introduction of Generic Attributes (GATT) profiles (see Figure 2), that define the way the communication between these devices is accomplished.

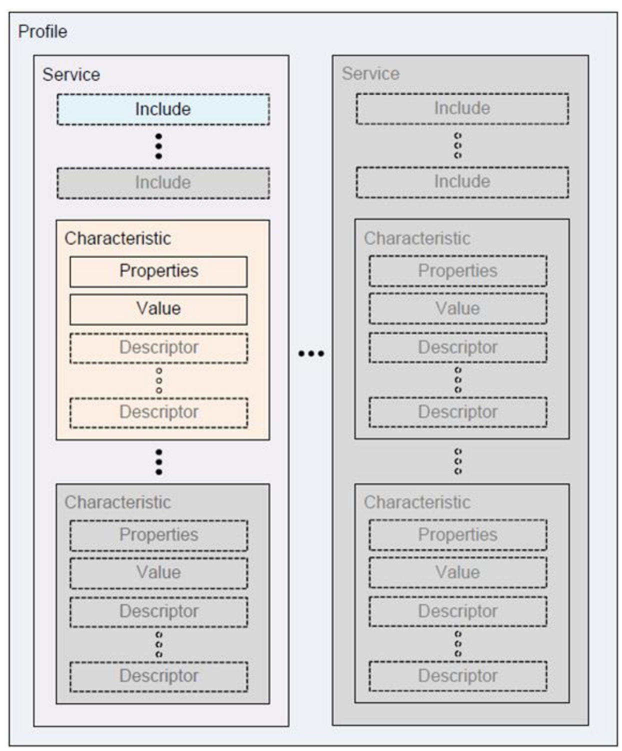


Figure 2 - GAAT Profile Hierarchy [13].

Observing the Figure 2, it is noticeable a hierarchical structure that has as the top level the Profile. Each profile defines a collection of services established by either Bluetooth SIG or the peripherical designer and detail how a device should work for any given application. An example of GATT-based profile specification is Glucose Profile and Heart Rate Profile.

In previous Bluetooth versions, the Serial Port Profile (SPP) was widely used to send bursts of data between two devices, since with a simple implementation it was possible to emulate a serial cable. In devices that use BLE, SPP is no longer supported and Microchip developed Microchip Low-Energy Data Profile (MLDP) to achieve this function. Although not recommended when designing an application that requires low energy consumption, it is a viable alternative when a stream communication is needed.

2) *Sigfox*

Sigfox is a pioneer network created for the IoT. In Europe, this technology has shown a lot of potential and its reach has been steadily expanding. Countries such as Portugal, Spain, France and Luxembourg already have full coverage and many other countries such as Australia and Brazil are getting there. It is expected for this technology to be available worldwide in the near future, continuing the deployment presently being done in the United States of America and spreading out from there.

Sigfox is indicated for objects that don't need to communicate a lot of data or frequently, since there is a limit of 12 bytes per message, and 140 messages per day that a device can send. Recently there was the implementation of downlink communication as well, establishing a maximum of 8 bytes per message and 4 messages per day. It is a low power, long range communication technology that has a low communication cost and relies on the 868MHz band which is part of the unlicensed spectrum [15].

One of the main features of this technology is that there is no need for network reconfiguration, which means that any new devices registered by Sigfox can become online without any need for installation, and new base stations can be added at will and immediately be part of the network. This makes Sigfox highly scalable and contribute for its fast expansion.

As for the transmission method, taking into account that each message occupies a really low bandwidth, many messages can be sent at the same time with little chance of collisions. Even in that case, the fact that each message is sent 3 times at different and random frequencies and frequently received by more than one base station creates redundancy, guaranteeing that at least one copy will arrive correctly, which is selected based on the strength of the signal received.

The messages transmitted are then stored in the Sigfox server and are easily accessed in two ways. The first is by logging in their backend's website where information about the user, the device and all the transmitted messages can be found. The other option is accessing it programmatically through their REST API, that uses HTTP protocol and returns the requested information in the JSON format.

B. *Smart Metering Communication*

Communication technologies in the context of AMIs tend to follow a few guidelines for their implementation to be considered. The measured data, whether it be energy, power, voltage or volume needs to be supported and there is a requirement for integrity of the transferred data, clock synchronization for the dynamic switch of tariff based on timetables, firmware update to fix eventual vulnerabilities or to add/improve features [17].

The energy market requires a big amount of information to be retrieved from energy meters so that the billing process and spending estimations can be as accurate as possible. This stresses the importance of a protocol that not only can collect data in different formats but is adaptable to future necessities, such as the addition of more functionalities.

1) *DLMS*

DLMS and COSEM define this protocol that is based on object modelling techniques, including object and interface classes. IEC 62056 is a series of standards for electricity metering data exchange and is structured based on a client-server model in which requests are made by the client and the corresponding data are replied by the SM [18]. These standards are the international version of DLMS/COSEM.

These standards define protocols and procedures for physical, data link, transport, and application layers By following these standards, it is guaranteed the interoperability between reading devices and meters from different manufacturers.

In order for the pair client-server be able to communicate, there is a need to create an Application Association between the two, and it falls on the client the responsibility to initiate the connection that will establish the association. Figure 3 shows the communication between client and server since the connection establishment to the connection termination.

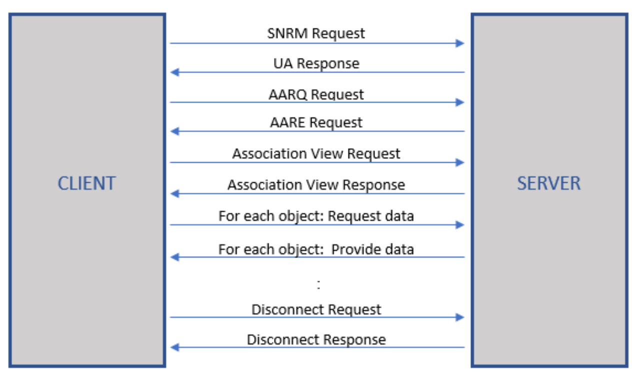


Figure 3 - DLMS Communication between Client and Server.

The SNRM Request is the starting point in any DLMS exchange and conveys the intent of the client of establishing a connection with the server. In this request and in the UA Response, the HDLC parameters are negotiated to achieve a successful information exchange. These parameters are optional in case both the client and server want to use default values. The next couple of messages consist in the Application Association Request (AARQ) and Application Association Response (AARE), which have the task of establishing, maintaining and releasing Application Associations (AA's), characterizing the context of the communication between client and server, including information such as access rights granted by the server to the AA.

After the establishment of a connection, all the information requests use standardized codes for all devices that are DLMS/COSEM compliant. These codes are named Object Identification System (OBIS), also commonly called logical names, being comprised by six octets each. There is some leeway regarding OBIS codes, since manufacturers can add their own codes for specific tasks that are not included in the standardized library [19].

The first request is commonly called an "Association View", and consists of the access by the client to the interface object model inside the server. With it the client obtains the list of visible COSEM objects made available by the server and the result of this exchange allows the client to request only the objects that are offered, receiving as a response the scale, unit and value of each one. The association is terminated once the necessary data is exchanged, and repeated every time the client wants to connect to the metering device. As an alternative, scheduled requests and subsequent replies can be maintained in an active connection, eliminating the need of consecutive connection establishments.

DLMS/COSEM is an international standard remarkably suited for the energy market. In [20], the DLMS User Association describes a few main reasons for the preference of this protocol above others. This explanation involved emphasizing that its interface model is usable in all types of energy, and supports future progression since objects can be added by manufacturers and new interface classes can be created without interfering with the previous services. Also, there are already classes defined for the most varied purposes such as tariff and activity scheduling and handling power failures. Other main concepts include efficient data organization, access and encoding. In Portugal this standard is the most used for smart metering purposes, usually over PLC or GPRS technologies.

III. Description of the Work

This section presents the proposed solution, describing the context of the project as well as how the used technologies were integrated to accomplish the objectives. The section is structured in three parts, beginning with the context, followed by the implementation of the smart meter and then by the Android application.

A. Monitoring of Voltage and Current in the LV Grid

This project is inserted in the context of the Smart Grid, and it came to be by having a significant and specific problem in mind that needs to be addressed, that is remote Low Voltage (LV) grid monitoring and control. This has gained significantly more importance due to the need to insert distributed energy micro-generation into the grid. But these technological improvements only came to emphasizes all the problems that were already present such as lack of means of detection of LV faults.

Unlike the High Voltage (HV) and the Medium Voltage (MV) grids, the traditional LV grid is seriously undeveloped and as such, does not have any mechanisms to actively regulate voltage and adapt to topology changes, that if implemented would give more control to the Distribution System Operator (DSO) as well as being more reliable to the end user.

A proposed solution is the voltage regulation by dynamic control of the active power injected by photovoltaic (PV) systems, that is now possible through the automation of distribution and monitoring that now part of the responsibility of secondary substations [2].

For the accomplishment of such solution, new equipment is needed for functions such as information gathering and exchange in order to be able to report the operational status of the grid, and actuation mechanisms to perform remote instructions on PV systems. This project proposes a SM that is able to not only perform local readings for a user, but also provide a means of communication between the Distribution Transformer Controller (DTC) and the PV controller for an automated regulation of the PV micro-generation and peak demands [21]. The DTC is installed in every Secondary Substation and acts as local metering, monitoring and automation devices.

The SM is part of each PV unit set since it will be located near a PV node. Figure 4 shows the overall environment that the developed SM is inserted.

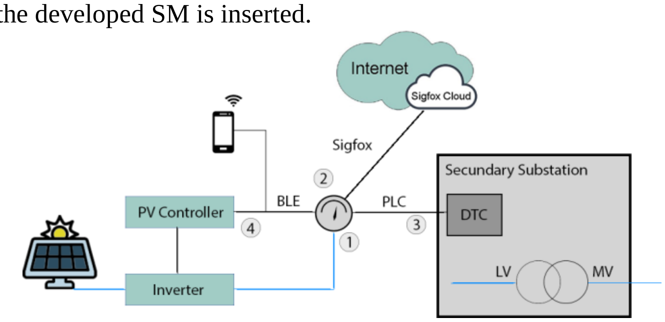


Figure 4 – LV monitoring and control system with SM.

The following steps are the ones that result through the direct involvement of the SM. It portrays a sequence beginning in the moment that the sensor in the SM relays the voltage, current and active power, to the regulation of the energy injection by the micro-generation system.

1. The SM performs regular energy readings;
2. These values can be read locally or remotely by the user, PV Controller and DSO, using Sigfox, and BLE as the communication technologies;
3. Via DLMS over PLC, the DTC will regularly enquire the SM of the values that were gathered, identifying peaks and demands. It will also check the LV grid power flow in order to calculate the power set point for each PV node, sending this information back to the SM;
4. Via BLE, the PV controller can read the adjustments to be made and perform the necessary regulations by automatically limiting the active power being injected by the PV inverter, per the DTC instructions.

Solutions like the one being here proposed need to be studied and implemented so the whole LV grid in general and all the components present in this architecture in particular, can technologically advance and a Smart Grid become a norm in any Smart City.

This solution recommends the standards and technologies to be used so that an effective communication can be performed with different key devices in the LV grid, offering the possibility of adaptation to more specific requirements or circumstances without losing focus on one important factor that is cost.

B. Smart Meter

The developed smart meter prototype aggregates several technologies in order to create a functional and innovative device, being suitable to both industries and homes. The information that is currently dealt in the project is the voltage, current and real power, and can be read using any of the following communication technologies: DLMS over serial port (e.g., PLC modem), BLE and Sigfox.

The board used as platform to the development of the proposed Smart Meter was the Akeru 3.3, which is an Arduino board. This board comes with a Sigfox modem and a half-wave antenna, and were added a BLE module, a push button, and an energy sensor to shape the SM that was designed.

There is an energy that was used to measure the voltage, current and power, and was created specifically for the Arduino used in this project. The use of this module was fundamental for the tests performed and a great tool to draw accurate graphs. For the software component, Open Energy Monitor [22] provides open source monitoring and their library for energy readings was used, offering the measurement of several variables, such as V_{rms}, I_{rms}, real power, apparent power and power factor.

The SM supports DLMS, which is an electricity metering standard, and exchanges information with the DTC over a serial connection, that could be implemented over PLC or GPRS. The use of this protocol is important due to its wide use and functionality, being an important communication tool for every metering device that communicates with utilities, since is allows the DSO to read the data and remotely configure set points. This technology was implemented and tested using a DLMS client example available for computers.

It supports BLE, which is a short range and low power technology that is used for local metering readings. This technology has the particularity of storing small amounts of data in its chip, making it readable, at any time, by another BLE capable device. This functionality was implemented in the Smart Meter to store the values using the RN4020 Bluetooth module. This allows the PV Controller to be continuously informed of any regulations imposed by the DTC.

Sigfox is also supported, presenting an innovative way of collecting data for large periods of time, simplifying the aggregation of data for statistics and plot generation. Given its long-range characteristic, not only are the values available for consulting in the Internet soon after they are sent, independently of where they are sent, but it is possible to send emails based on abnormal or malfunction values. The Smart Meter has the task of evaluating and sending the messages using the Sigfox antenna incorporated in the Akeru board.

Figure 5 contains a flowchart of the program created, giving a visual aid in understanding the overall process involved. As can be observed, the flowchart depicts a sequence of events that runs through all the technologies used in the project. It was developed this way because it only has one task done regularly that is the BLE data update. The Sigfox transfer only occurs in periods of 30 minutes or in case of detection of abnormal values, and the DLMS transfer in a periodicity defined by the DTC but not frequent in nature. This means that only when one of these last communications is occurring that some small delay may happen, but otherwise the expected duration of the cycle is not disturbed.

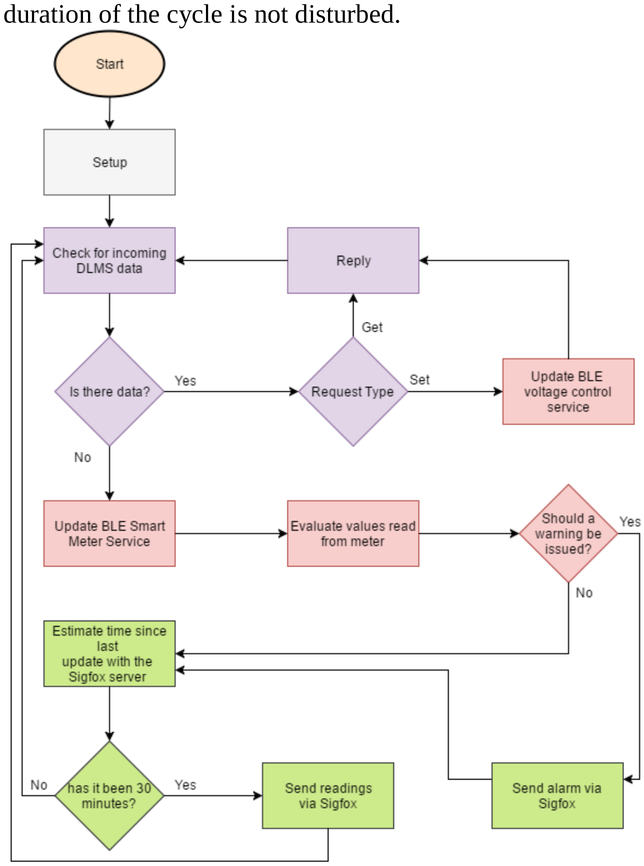


Figure 5 - Flowchart of the program

1) DLMS

To provide a viable communication between a client and server, verifying the validity of the replies delivered, this specific server followed the message exchange available in the Gurux client application. This application can send all the client messages that are needed for a simple yet successful and informational data exchange, and the answers that the server must create to correctly reply were formed with the aid of the books of the DLMS User Association

As per the DLMS specifications, the client is the one that initiates the connection with the server, so the Arduino continually checks for incoming data via the serial port, specifically searching for the initial delimiter character of a DLMS frame.

When the device recognizes that a DLMS frame is being received, the content of the message is stored and each byte is processed. The processing phase of a frame includes, among others, the verification of its validity and the identification of the type of content available in the message, rapidly distinguishing between the various kinds of requests available. All the valid frames that are possible to create with this protocol follow a strict structure and order that needs to be fulfilled in order to be possible the proper interpretation of the message.

Since not all clients are equal, nor all servers, some error messages were programmed in the server so that if it receives a message that it does not recognize, an appropriate reply is transmitted and the connection can continue. It should be noted that a default client application only waits a variable pre-programmed amount of time without receiving a valid message before dropping a connection.

In this server, data blocks are not available since at the time of completion of the program the client example application did not support it. Although it is now supported by the example used, it is not a demanded feature by any DLMS client so an error message was implemented to inform the client that a single block request needs to be sent. The other error messages inform the client that the requested object or attribute (i.e., value or scale) is not available.

Once a successful connection is established, the inquiry of an "Association View" is possible, although not mandatory. But nonetheless it was employed and replies the list of objects available. The steps after that concern the actually exchange of needed information, and in this case, the voltage, current and active power were implemented. The server, for these object, not only sends the measured values, but also the unit and scale. See Table 1 for the relation between the OBIS codes used in the server and their translation.

Table 1 - Implemented objects.

Name	OBIS Codes
Association View	0.0.40.0.0.255
L1 Active Power Value	1.0.21.7.0.255
L1 Current Inst. Value	1.0.31.7.0.255
L1 Voltage Inst. Value	1.0.32.7.0.255
Measurement Algorithm: Active Power	1.0.0.11.1.255
Measurement Algorithm: Reactive Power	1.0.0.11.3.255

The last two objects represented in Table 1 are not the type `Get-Request` like the other messages, but a `Set-Request`. This means that when a message containing one of those OBIS codes arrives, the DTC is not inquiring for any object or value, but sending a power set point that needs to be stored in the BLE module to be read by the PV controller. This type of request only expects a response consisting of an acknowledgment message.

This DLMS server implementation always waits for a disconnection request from the client to sever the connection, and this means that, between the SM and the DTC, the connection can be permanently established and ready to send out measurements if that is the choice made in the implementation of the DTC.

2) BLE

The BLE technology was inserted in this project with the objective of providing a low power, short range communication that is able to have constant updated information, and is easily integrated with a mobile device.

The BLE module will have a permanent connection with the PV controller, so that it can perform a continuous verification of any limitation imposed by the DTC for immediate execution. It is possible to interrupt this connection using a push button in the meter when a prosumer has the intent of consulting the readings using a smartphone.

The implementation of BLE in the Arduino involved having frequent and periodic meter readings that are to be stored in the Bluetooth module, and power updates made by the DTC that are not periodic in nature. These two types of updates are stored in different services and each type of data has its own characteristic.

3) Sigfox

The Sigfox plays a simple but significant role in the communication the Smart Meter has with the outside world. While the DLMS and the BLE components provide mostly instantaneous readings for reading on-the-fly, the Sigfox component collects the average calculated values to transfer to a cloud server where they are permanently stored, for later manipulation into a visual component that gives insight into the consumption of energy over time.

Regular updates are made estimating periods of 30 minutes between each transfer. These contain the calculated average values read between each update, in order to provide accurate data for later presentation in a plot, giving the user insight on the voltage and current measurements in any period of time.

The cumulative energy presents the energy consumption values every 24-hours, in kilowatt-hour (kWh), and it is reset after each transfer. This information is vital for the user to understand the average values of consumption-generation balance throughout the day and estimate costs or earnings at the end of the month.

The last type of message refers to warnings, meaning that it shows the user every value measured above or below a certain threshold. For the voltage, expression (1) was used to calculate the maximum and minimum values of the threshold. The current only presents values if above a default limit of 26A.

$$U = \pm\, 0.1 \times \frac{U}{\sqrt{3}} = \pm\, 0.1 \times U_0 \qquad (1)$$

C. Android Application

The Android application was developed using Android Studio, which is the official IDE from Google, and provides an easy access to the SM by the user., since it enables the visualization of data made available by two of the communication protocols studied in this project: BLE and

Sigfox.

It was created with the intent of being a simple but useful tool for the final client, where are made available the instantaneous voltage and current readings via BLE, and a plot with data collected via Sigfox for an overall idea of the SM consumptions throughout the day. The Sigfox component also provides the latest warnings, which are a compilation of messages relating abnormal situations, and also shows the cumulative power readings over 24-hour periods. The next sections detail all these components.

1) BLE

Google offers open source code for multiple functionalities and these are easily downloaded for use in any application being developed. In this particular case, BLE code sample, BluetoothLeGatt, is available and was integrated in the Android application developed with only one prerequisite of SDK version 25 or higher. This application uses BLE APIs used to discover devices, send and receive data, and interact with nearby sensor devices like Google Beacons [49], [50].

The BluetoothLeGatt sample contains an interface where a user can visualize nearby BLE devices and establish a connection with the one needed, displaying data, services and characteristics available in the device (see Figure 6).

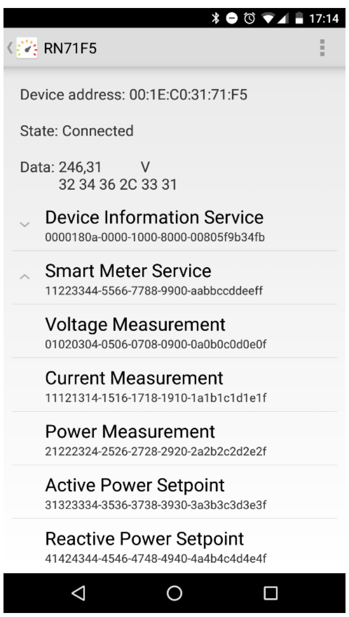


Figure 6 - BluetoothLeGatt in the SM Application

In the Bluetooth code sample used, some details were added for a better readability of the characteristics available, such as names for the service and characteristics used, and for the determination of the scale of the values that are available to read.

2) Sigfox

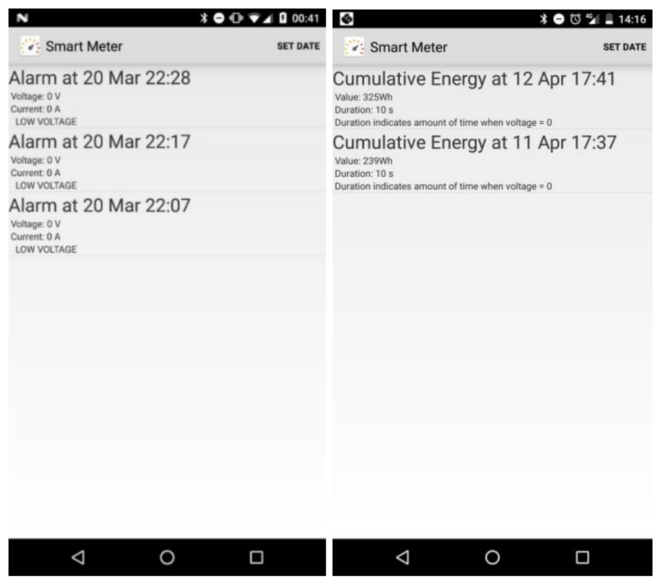
Sigfox provides a way for data to be accessed programmatically through a REST API, using HTTP protocol. It returns the requested information in the JSON format.

In order to be used in the Android application, the use of the class `HttpURLConnection` was needed to request the information and receive the data transmitted. For the processing of the data, the class `JSONObject` was used, simplifying the method of identifying each JSON object inside a JSON array, and each data type and corresponding information, inside the JSON object.

The application has menu that contains the choices a user can make regarding information that is available in the Sigfox server. The buttons open new activities, generating lists or plots adequate to the content that is presented. Each of these activities retrieve all the JSON data until a predetermined number of messages or a predetermined data and filter the ones needed by a code present in the beginning of the message. All the activities presented contain a button for the editing of the data in order to show past measurements.

All the information that can be seen in the screenshots of the Android application is based on real values of energy consumption so that they would be represented in the most realistic way.

The first item in the menu contains any warnings sent to the Sigfox server in the previous 7 days. Figure 7-a shows how these values are presented.



(a) (b)

Figure 7 – Android App (a) Warnings; (b) Cumulative Energy.

The second item of the menu contains two 24-hour plots, one for voltage and one for current. These plots present the average values for every 30 minutes, providing a visual aid for all the fluctuations that happened in the balance of energy production-consumption. Figure 8 shows an example of graphs that can be seen in this section.

To draw these plots, Androidplot was used. It is a library for Android that enables the creation of dynamic and static charts. In this case, a static plot was designed since these values are only updated once every 30 minutes. The plot presented in the Figure 8 has real data is an accurate small scale representation of the general consumption in a house, with higher voltage and lower current values during the night, and several current peaks throughout the day.

The third item of the menu contains a message per day, up to 7 days, with the computed energy consumption. Since anomalies in the voltage values can significantly change the outcome of this value, another variable was included which is the number of seconds that the values were over or below the threshold. Figure 7-b shows how these values are presented.

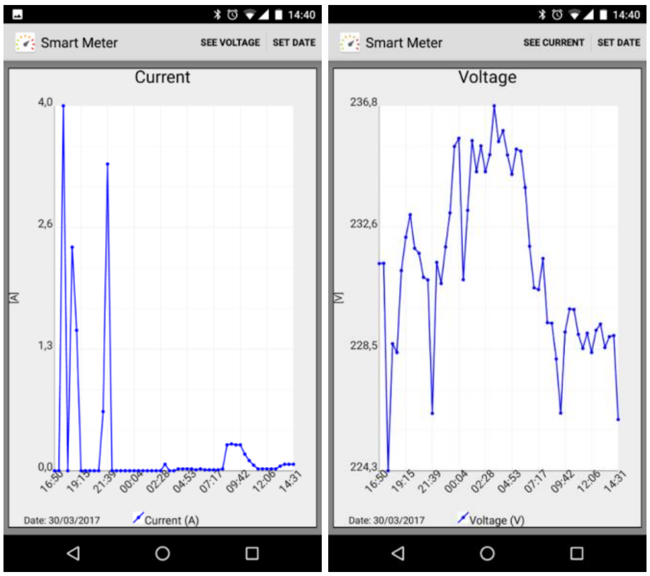


Figure 8 – Voltage and Current plots.

IV. Appraisal of the Solution

The hardware used in this project was chosen considering the functionality it was required and availability for testing purposes at the time. The general characteristics that were taken into account in the choice of hardware were energy efficiency, cost and ease of use. For each technology, a set of more specific attributes were considered.

A. Developer Board

While Raspberry Pi is a single-board computer, both Arduino and STM32 are micro-controllers. Each of these devices should be used according to the type of project one is trying to develop. In the case of this dissertation, we need a device that can easily read sensors, can execute communications using different protocols, is power efficient and low cost. Using Raspberry Pi to perform these tasks would be more complex for the analog reading necessary and would require more interaction once operational, and it has a higher power consumption and cost. All these requirements point to the use of a micro-controller instead of any Raspberry Pi, limiting the final choice to an Arduino or a STM32 board.

Between Arduino and a STM32 board, both are highly capable of offering the attributes necessary to the development of this project so the decision comes greatly from the factor that, at the time of the testing of this technology, the acquisition of a Sigfox module for single and personal use was more complicated and expensive than large scale buying, and the same for the yearly subscription. It was available the Akeru 3.3 board, which is an Arduino board, with a Sigfox module and antenna already integrated that facilitated the accomplishment of the proposed SM prototype. It is important to note that this project could be done in either of these families of boards, if the minimum requirements to run the program are fulfilled. See Table 2 for the minimum requirements.

Table 2 - Minimum required technical specifications.

Type	Min. required	Used
Flash Memory	32 KB	17.618 B
RAM	2 KB	1.488 B
Digital I/O Pins	6	6
Analog Input Pins	2	2

An assessment of the price of these components and the overall cost of the developed SM was done, in order to obtain a cost appraisal.

Table 3 shows the minimum price found for the developer boards that are the least expensive in each family, but still fit the minimum required technical specifications. These values represent the unitary cost, that would be reduced if bought in large quantities.

Table 3 - Cost of the Developer Boards.

Developer Board	Cost
Arduino Uno [51]	€20
STM32 Discovery [52]	€9

B. Sigfox module

A LPWAN communication technology is a key point in this project, since it provides reliable data independently of where it is located and without the need to build a supporting network. Three technologies that fit the criteria were studied, but Sigfox was the one that provided the solution that was more adaptable to the plan.

At this point in time, NB-IoT is not commercially available but is an emerging powerful technology that should be carefully considered for future projects that involve Smart Grid or IoT devices. LoRaWAN also is still a recent technology that does not have the wide coverage provided by Sigfox.

Sigfox was considered the most advantageous LPWAN solution for this implementation. With several deciding factors distinguishing both, the two that were more significant were the slightly higher cost of LoRaWAN and the fact that there is no LoRaWAN operator in Portugal at the time of conclusion of this project.

For the Sigfox appraisal, several shops were found and each offered different prices and set of components. Although there are several different modules available, since they offer the same functionalities, only the least expensive component of each needed type was included, and they were separated into categories. For a complete assessment, the cost of a yearly subscription was needed but these values are not available online for the common user. It is expected that large scale buying reduces the unit cost very significantly. Table 4 shows the unit cost of the Sigfox components when bought piecemeal.

Table 4 - Cost of the Sigfox components.

Components	Cost (unit)
Module – ATA8520 [53]	€2,21
868 MHz Antenna – 888-A08-HASM-560 [54]	€8,49
Subscription	Not available
Sigfox module + Antenna + Subscription [55]	€66

In the development of this project an Akeru 3.3 was used, since it already has Sigfox incorporated and a valid subscription offered by Narrownet, the Sigfox operator in Portugal.

C. BLE module

A low power, short range communication technology was considered for the purpose of facilitating the transfer of small amounts of data for quick consultations or adjustments. The technologies considered were ZigBee and BLE, and an assessment of both was conducted. BLE was indeed the most suitable choice considering it is already integrated in smartphones.

There are currently many manufacturers for BLE modules, and choosing a specific model was not an easy task. One of the features that were a determining factor was the support of an asynchronous serial data connection between devices, for the possibility of implementing remote configurations on the BLE module or even serial communications, if the situation required it. This meant that the pool of possible modules was shortened since Microchip is the only manufacturer that provides MLDP, which is a proprietary protocol for this type of communication.

Considering only Microchip modules that support MLDP, the two most adequate and cost efficient are the RN4020 and the RN4871 both having similar characteristics and compatibility with each other. The latter is presented as the next-generation BLE device with lower power consumption and improvement in the data throughput.

The module used in this project was the RN4020 since the newest model was not yet available when this project was initiated. Table 5 shows the costs of both models, showing a lower price for the newer model, being even more favourable for the integration in this project, since it offers the possibility of creating more than one private service, unlike the RN4020 module.

Table 5 - Cost of the BLE module.

Module	Cost (individual)	Cost (100+ units)	Bluetooth version
RN4871	€5,11	€4,68	4.2
RN4020	€7,75	€6,68	4.1

D. Final Solution

The overall cost of the final solution is calculated having into account the least expensive components that are or could be integrated without significant changes in the performance or consumption of this project. It is later compared with existing SMs so that the value present can be related with existing solutions.

Table 6 shows the best components for this solution, having into account both the technical characteristics and the cost. It is important to note that these values are only in effect when buying piecemeal and if bought in large scale the overall cost would be significantly lower.

Table 6 - Cost of every component of the best solution.

Component	Cost	Observations
STM32 Discovery	€9	Push button included in the board
RN4871	€5,11	--
Sigfox solution	€66	Significantly lower with large scale contract
Energy sensor	€7,5	Estimated
Total Value	€87,61	Worst case scenario

Although these components are not the ones used in the solution of this project, they offer the same features and are in the same price range so that the solution is expected to perform the same as the ideal solution projected above. The reason for this change is the fact that some of the used components were the ones currently available in the market or were the best way to test a specific technology, given the circumstances.

To provide a way of determining if the cost of the proposed meter is affordable, a market analysis was conducted to evaluate the price range of the products available in online shops. Unfortunately, none of the devices that have characteristics like this one presented any prices, and every metering device that had a cost associated lacked many of the key features necessary for a fair comparison.

These devices, like the prototype developed, are single phase, but lack any wireless communication technology (except infrared), preferring Modbus or RS485, and many do not support DLMS. Still, the price range goes from €70 to €400.

V. Conclusions

Considering the current opportunities for the installation of energy micro-generation systems in houses and commercial buildings, innovative ways of monitoring and controlling the bi-directional energy flow in the LV grid need to be created, thus allowing for an effective organization of the prosumers production and consumption by the DSO aiming for the grid stability. The existing electric grid is inadequate for the type of regulation that the distributed systems need, and does not allow for the implementation of mechanisms that these systems can provide. This is the case of fault detection in the LV grid and topology changes when they are needed.

The developed SM prototype is intended for the use near a PV node, performing local energy readings to be consulted by the prosumer, and aiming to facilitate the communication between the PV controller and the DSO, for a remote monitoring and control, automatically limiting the active power being injected by the PV inverter.

This was accomplished by implementing several innovative communication technologies to transfer data in the most efficient and adequate way for each required exchange. Therefore, DLMS, a standard for energy communication was implemented for transfer of data with the DSO via a serial interface (ex.: PLC). BLE, a low power short range technology was employed to make available regular instantaneous energy readings to be consulted by the prosumer, and instructions sent by the DSO to be read by the PV controller. And Sigfox, a low power long range communication technology, that stores average voltage and current readings for an analysis to the balance of energy consumption and generation, and generates alarms of abnormal situations.

The prototype presented does provide the functionalities and characteristics proposed, being an improvement to the systems currently in place by assisting both the utilities and the prosumers. Since there are not many products for commercialization to the end user with the characteristics deemed vital for a SM, the economic component does not present precise values, but an approximate assessment can be made by looking at the cost of baseline standard SMs, and finding these to cost at least near the worst-case scenario production cost of the prototype, being in many instances much higher. This product would cost significantly less in a commercialization phase, certainly achieving a lower price than the products currently in the market.

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