



**ASHESI UNIVERSITY COLLEGE**

**Home Automation:**

**Real-time Electricity Consumption Monitoring and Remote Home Appliance Control**

**APPLIED PROJECT**

B.Sc. Computer Science

**Kingsley Amoaning-Yankson**

**2018**

**ASHESI UNIVERSITY COLLEGE**

**Home Automation:**

**Real-time Electricity Consumption Monitoring and Remote Home Appliance Control**

**APPLIED PROJECT**

Applied project submitted to the Department of Computer Science, Ashesi University  
College in partial fulfilment of the requirements for the award of Bachelor of Science degree in  
Computer Science

**Kingsley Amoaning-Yankson**

**April 2018**

## DECLARATION

I hereby declare that this applied project is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

.....

Candidate's Name:

.....

Date: .....

I hereby declare that preparation and presentation of this applied project were supervised in accordance with the guidelines on supervision of Applied project laid down by Ashesi University College.

Supervisor's Signature:

.....

Supervisor's Name:

.....

Date: .....

## **Acknowledgment**

I would like to show gratitude to my main supervisor Dr. Nathan Amanquah and the entire computer science department for the guidance and assistance in moving this project from the ideation stage to a reality. I would also like to show special gratitude to Mr. Nicholas Tali for his help, direction and contribution to this project as well Ms. Adwoa A. Aboah for the support and guidance throughout the project.

## **Abstract**

Internet of things (IoT) has provided an opportunity for technology to be used to solve more complex problems and understand a lot more processes and activities by collecting and analyzing data. The growing demand for electricity in Ghana has been coupled with the increase in cost of providing this basic amenity. The homeowner has been burdened with high electricity billing, which has led to the adoption of life changing recommendations. Home automation technology has provided a means of effectively monitoring electricity consumption and remote control of homes. Unfortunately, this technology has not been leveraged in solving the problem of high electricity billing in Ghana. This project has built a system that leverages IoT technology in creating a cost-effective real-time electricity monitoring and remote-control system. The System helps its users to reduce their electricity consumption by helping him/her ensure appliances that are not in use can be turned off remotely, provides a visual representation of consumption data and a threshold setting feature for monitoring total daily/monthly consumption.

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# Chapter 1: Introduction

## 1.1 Background

Ghana has witnessed several spikes in electricity tariffs, which have been the consequence of solutions put in place to curb the energy deficit in the country. In 2015, the Ghanaian government rolled out measures to correct the energy challenge in the country, which included the establishment of an energy debt recovery levy, energy sector levy, commissioned a thermal power plant in Kpone and docked a power batch on Ghanaian soil (Clerici, Taylor & Taylor, 2016). All these efforts were geared towards solving the power issues that had plagued the country in 1983, 1998, 2006 and 2007 (Clerici, Taylor & Taylor, 2016). These actions taken to curb the problem of “dumsor”– the term used to refer to frequent power outages in Ghana– were coupled with repercussions which are still being experienced today.

The biggest repercussion has been the increase in cost of electricity. As mentioned earlier, since 2015, electricity tariffs have increased over 100%. According to statistics from the Electricity Company of Ghana’s website, tariffs have moved from 15 pesewas per unit to 34 pesewas per unit in the past few years (ECG, 2017). ECG equates the need for the hike in prices to rising cost of production, growing energy demand and the fall in the cedi. Since the inception of these increments, customers have been disgruntled and disheartened by the new changes introduced by the Electricity Company of Ghana (ECG). In an attempt to help customers deal with the increase in tariffs, ECG has advised customers to reduce their electricity consumption. There have been several campaigns organised to educate the general public on how this can be achieved. Most of these campaigns place the onus on the individuals of households to implement suggestions which may change their way of living

## **1.2 Aim**

This project aims to tackle the issue of high electricity bills by reducing electricity consumption and improving electricity monitoring in homes seamlessly. This project will focus on using home automation technology to help homeowners reduce electricity consumption.

## **1.3 Problem Statement**

Over the past few years, homeowners have resorted to drastic actions that have affected their comfort in order to reduce their electricity bills and accurately monitor their consumption. The issue lies in finding ways of monitoring and reducing electricity consumption without drastically affecting the comfort or way of life of a household. The unfortunate situation of high tariffs has been the bane of most homeowners and the majority of the Ghanaian population. The use of home automation systems to monitor and reduce electricity consumption have proven to be an effective solution. Unfortunately, this type of system may be expensive to import and has not been widely designed and developed for the Ghanaian community.

## **1.4 Proposed Solution**

The project proposes to delve into home electricity monitoring by giving real-time updates of the electricity consumption to users via mobile devices. This data will be analyzed using data analysis models and techniques in order to make suggestions to homeowners on ways to cut down consumption.

The spectrum of quantities obtained from analyzing voltage and current signals for a particular device in a frequency domain is said to be the electrical signature of that appliance, which is unique to that device (Salomon et al., 2017). By studying the electrical signatures of appliances, we can determine when they are switched on and how much energy they consumed. This will enable us to inform the home owners of the usage patterns of his devices and appliances in their home, showing them when the electricity consumption is above a particular set threshold.

. Another problem this project seeks to solve is controlling lighting and appliances in the home remotely. With the information obtained from the monitoring and mining processes, we can switch off appliances and lights that are not in use but are consuming power. This project is targeted at homes in Ghana where the smart home technology has not been developed, and as such it would be a feasible implementation of home automation in Ghana for homes that have already been built. It will be relevant to any homeowner who would like to reduce their electricity consumption and have the ease of controlling his/her home remotely, thereby creating a pool of potential customers.

### **1.5 Project Objectives**

- Provide a platform to enable homeowners to control appliances and lighting remotely.
- Provide real time monitoring of electricity consumption.
- Provide an intelligent system that can help reduce electricity consumption in homes seamlessly.

### **1.6 Benefits of Proposed Solution**

The implementation of this project will deliver several benefits to the user, which include savings, increased energy efficiency, and security against electrical fires. Judicious users of the proposed system will realize a reduction in their electricity billing. Since electricity consumption is directly proportional to one's electricity billing reducing consumption will result in an equally proportional reduction in electricity billing. The ability to control devices in the home will make it possible to ensure appropriate use of systems and appliances. This will allow users to **save** money and energy.

With regards to increased **energy efficiency**, this system would make it possible to see the implications of one's actions, habits and lifestyle on the consumption of electrical energy in the home. This would be useful to the customers who will be able to monitor and see the amount of electricity units being consumed by the current usage. The system will help make a customer's

consumption easy to understand, which will also make it easier to choose from recommended preset actions in order to reduce electricity bills and save energy.

Yet another benefit would be the peace of mind introduced by the increased **security against electrical fires**. According to the GNFS (Ghana National Fire Service), there were about 2,469 fire out-breaks within the first quarter of 2016. Of this number, 145 of these fires were said to have been electrical fires and 70 of these electrical fires were domestic related fires. (Ghana Business News, 2016). It is very common for someone to leave their home and forget to switch off certain appliances such as stoves, irons, electrical heaters, kettles or lights, and these things have the potential to cause a fire. The proposed system will allow homeowners to view the power status of all their appliances or devices on the system from anywhere via Wi-Fi connection, as well as enable them to turn off any of these appliances remotely. This will give homeowners the peace of mind knowing that, for example, their irons will not burn down their homes.

## **1.7 Related Work**

As a result of the increasing interest in the concept of Internet of Things (IoT), home automation has become a field of application and intense research. However, very little literature exists on the implementation of home automation in Ghana. This subsection will cover existing technologies and previous work done in the field of home automation.

A research and feasibility study conducted in 2013 by Ming Yan and Hao Shi focused on controlling devices connected to a Bluetooth controller module (Yan & Shi, 2013). The user terminal of this system was connected to the controller via an android phone's native Bluetooth capability. However, one major problem with this system was range. The Bluetooth technology has not been designed to cover large distances and hence limited the possibility of remotely controlling the system.

Another similar project dealt with developing an affordable solution that will enable remote control of home appliances and also serve as a security system (Sikander Hayat Khiyal, Khan & Shehzadi, 2009). This project focused on using SMS to control the monitoring subsystems. It was built using a microcontroller, General Packet Radio Service (GPRS) modem/ cell phone and a sensing unit. The project was undertaken by Ciubotaru-Petrescu, Chiciudean, Cioarga, and Stanescu in 2006. One of the downsides identified in this approach was the inability to transmit several commands in one SMS, hence, increasing the latency of the system as it has to go through several different SMS messages.

In 2003, Potamitis, Georgila, Fakotakis, and Kokkinakis, G. proposed a home automation system that used speech as a natural input to interface with connected appliances remotely (Potamitis, Kokkinakis, Fakotakis & Georgila, 2013). It focused on providing a hands-free alternative for home appliance control which would be a handy tool for most people with some form of disability (Potamitis, Kokkinakis, Fakotakis & Georgila, 2013). This system however faces the potential of misinterpreting commands as a result of the accented speech of Ghanaians and several other nationalities.

This project shows uniqueness in the manner in which information gathered from appliances is transmitted and presented to the user. The underlying technology of MQTT provides added advantages such as security robustness and quality of service.

## **1.8 Overview of Chapters**

This paper contains seven chapters. The first chapter introduces readers to the entire project at hand and gives some information about the background of the problem being tackled. A brief description of the proposed solution is accompanied by the benefits to be derived from the successful implementation of the solution and related work. Chapter 2 explains important concepts and principles needed by the reader to understand the project. This chapter also brings to light some existing solutions and discusses the available technologies that can be used in the development of the solution. Chapter 3 presents a highly detailed description of the various requirements the system must satisfy. Chapter 4 details the underlying methodology going to be used in the design, structuring and implementation of the proposed solution. It will highlight the different components and architecture required to implement the solution. Chapter 5 summarizes the implementation and development process of the system. The sixth chapter deals with the testing and results, the proposed system produced after implementation. The last chapter discusses the problems, limitations and future work of the system. It also summarizes the entire project and what has been achieved.

## Chapter 2: Important Concepts

This chapter will explain the concepts that are intricate to the understanding of the project as well as bring to light the possible technologies available for carrying it out. The literature review conducted will be used in this chapter to highlight previous work done in electricity consumption and monitoring. To achieve a better understanding of this project, certain key concepts and research work done in this field of home automation and internet of things (IoT) is explored.

### 2.1 Internet of Things (IoT)

The concept of IoT is a fast-growing field of technology which allows technologists to improve an existing process or solve a problem, by gathering information about the process or the problem in question. IoT can be described as a network of connected objects, devices, or embedded systems that gather information from the environment through sensors or enable actions in the physical environment through actuators. These devices may convert information obtained from the real-world environment into digital data that can provide more insights and better understanding of how people interact with anything ranging from a product, a service or electricity consumption (Navani, Jain, & Nehra, 2017).

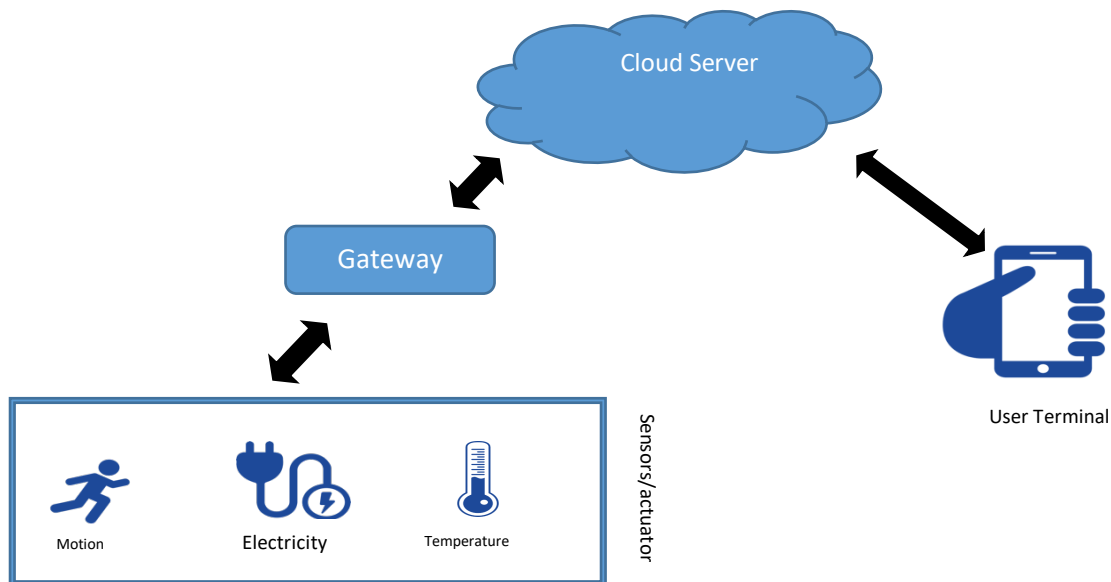


Figure 2.1 : IoT architecture

The Figure 2.1 shows the basic architecture of an IoT system. It is made up of sensors that interact with the real world collecting data that is sent to a cloud server via a gateway. The gateway enables sensor devices to connect to the internet in order to reach cloud services. The user terminal connects to the cloud server over the internet to access processed data or send instructions to sensors and actuators to achieve an action.

## **2.2 Home Automation**

One application of IoT is the idea of home automation. The term home automation is used to refer to the introduction of technology into homes with the aim of enhancing the quality of living for the inhabitants, through the provision of several services such as energy conservation, security and entertainment (Gill, Yang, Yao, & Lu, 2009). One of the fundamental concepts that is making this technology possible is Internet of Things (IoT). This essentially makes it possible for objects to collect data from the environment and communicate it by harnessing underlying technologies such as embedded devices, pervasive and ubiquitous computing, communication protocols and sensors networks. The next subsection will focus on technologies available for carrying out machine-to-machine communication.

## **2.3 Messaging Protocols**

In achieving machine-to-machine communication, which is the heart of IoT, there are several protocol options that can be considered. Some of these technologies have helped make possible the real-time communication needed in the development of Internet of Things (IoT) application possible. These technologies are known as messaging protocols. They tend to be responsible for transporting messages from end to end within a communicating and collaborative network of devices. The idea of home automation deals largely with Machine to Machine communication (M2M) and user control. There are several messaging protocols that have been



developed for the purpose of IoT. This section will discuss four different possible messaging protocols that can be used to achieve our intended goal.

One messaging protocol is **Message Queuing Telemetry Transport (MQTT)**, which is considered the oldest lightweight M2M protocol for communication in constrained networks. It is a messaging protocol which works on a principle of publish/subscribe to communicate messages between machines (Naik,2017). A machine (client) that would like to send out a message to other machines would publish its message to a cloud server called a broker. Every message that is published to the broker is done to a particular address referred to as a topic. This broker then distributes the message to all clients that are subscribed to the particular topic the message was published to. A client can be subscribed to multiple topics and can also publish to multiple topics. MQTT protocol deals with a fixed header of size 2-bytes and a payload of 256 MB maximum (Naik,2017). It tends to use the TCP as its main protocol for transport and dwells on TLS/SSL for its security. It is designed with a three tier Quality of Service (QoS) system which helps make delivery of messages reliable (Naik,2017).

Another messaging protocol is **Constrained Application Protocol (CoAP)**, which is also a lightweight machine to machine communication protocol. This protocol is designed to work with HTTP and the REST web API. It operates on a variation of the publish/subscribe module called the resource/observe and the request/response architecture. Messages are passed by publishers publishing messages to particular URL (Universal Resource Locator) which other clients have subscribed to (Naik,2017). The CoAP just like the MQTT protocol is a binary protocol but uses a fixed size header of 4 bytes (Naik,2017). The maximum size of the payload attached to the header is dependent on the server it is associated with or the programming behind it. It uses UDP as its transportation protocol and hence suffers reliability issues. It has more functionalities than MQTT does but also has only two levels of QoS (Naik,2017). It uses datagram transport layer security (DTLS) which provides security for its datagram communications.

**Advanced Message Queuing Protocol** is another machine to machine messaging protocol developed for the corporate world with provisioning made to cater for security, provisioning and interpretability (Naik,2017). Its architecture is similar to that of CoAP's request/response and publish /subscribe architecture. It is extensively developed and has a wide array of features ranging from reliable queuing, flexible routing to publish and subscribe modules. It however has added details with regards to its publish-and-subscribe module architecture. Each publisher or consumer uses the name of an exchange which was created to identify each other. For clients, it has an additional overhead which involves binding messages received from the exchange to the queue it maintains. It is also a binary protocol but requires a fixed 8-bytes header. The maximum size of the payload attached to the header is dependent on the server its associated with or the programming behind it. It tends to use TCP as its protocol for transport and hence uses TLS/SSL SASL for security (Naik,2017). One of its core characteristics is reliability, and hence ensures communication channels between client and broker are established before messages are sent. It primarily has two levels of QoS for message delivery: settle format and the unsettle format (Naik,2017).

Another messaging protocol that could be used to achieve our goal is the **Hyper Text Transport Protocol**, popularly known as HTTP. It works on the request/response REST Web architecture (Naik,2017). This protocol uses the Universal Resource Identifier (URI), with which it sends data to the client and server. It does not have a fixed size header since it is a text-based protocol, however the payloads are dependent on the web server being used and the programming behind it. It relies on TCP for a connection-based transport and TLS/SSL for security Naik,2017). HTTP has been extensively developed and very popular in the web messaging sphere.

## **2.4 Chapter Summary**

IoT has made it possible to carry out ubiquitous sensing, which provides the opportunity measure, infer and understand data collected from the environment. The power provided by machine-to-machine protocols has also boosted the concept of IoT and its application in homes. In creating this system the project will leverage advancements made in this area of IoT and home automation to achieve the intended goal of reducing of electricity consumption in homes. It will however make use of the MQTT protocol to carry out machine-to-machine communication. This choice was made because of the quality of service it provides, the provision of a central broker, security provided by TLS/SSL feature, the lightweight nature and large support pool available.

## **Chapter 3: Requirement Specification**

This chapter comprises a detailed description of the project scope as well as the functionality it would offer the users of this system. It will also highlight the functional and non-functional requirements of the system. The system will be called Ma Maison Home Automation System. The chapter also goes on to discuss the different classes of the targeted niche of users.

### **3.1 User Identification and Use Cases**

This home automation system is meant to be used primarily by homeowners and other people who reside in the home where the system is installed. To provide a better perspective of how the application may be used, below are some use cases.

1. A homeowner who is late for a meeting leaves home abruptly and forgets to turn off his electric stove after making breakfast. The thought crosses his mind and he goes into the Ma Maison mobile app and turns it off.
2. A homeowner who wants to monitor his electricity consumption sets a threshold for his monthly or daily consumption. He receives an alert when this threshold is exceeded and suggests automated settings that would keep him under the threshold the following month or day.
3. The son of a home owner is always forced to switch on and off the outside lights in the house every day and he sometimes forgets to do this. The homeowner using Ma Maison automates the turning on and off of all lights in his home connected to the system.

### **3.2 Project Description and Scope**

Ma Maison Home Automation System will be made up of four communicating components;

- the IoT devices switchboard which will receive and transmit signals to and from appliances.

- the cloud service which will handle communication between user interface and switchboard devices.
- the PHP server side and MySQL database which will handle storage of historical data and transmission of data to mobile application.
- the mobile application used by the user to interface with the entire system.

The system will allow users to monitor their electricity consumption in real-time as well as control all home appliances.

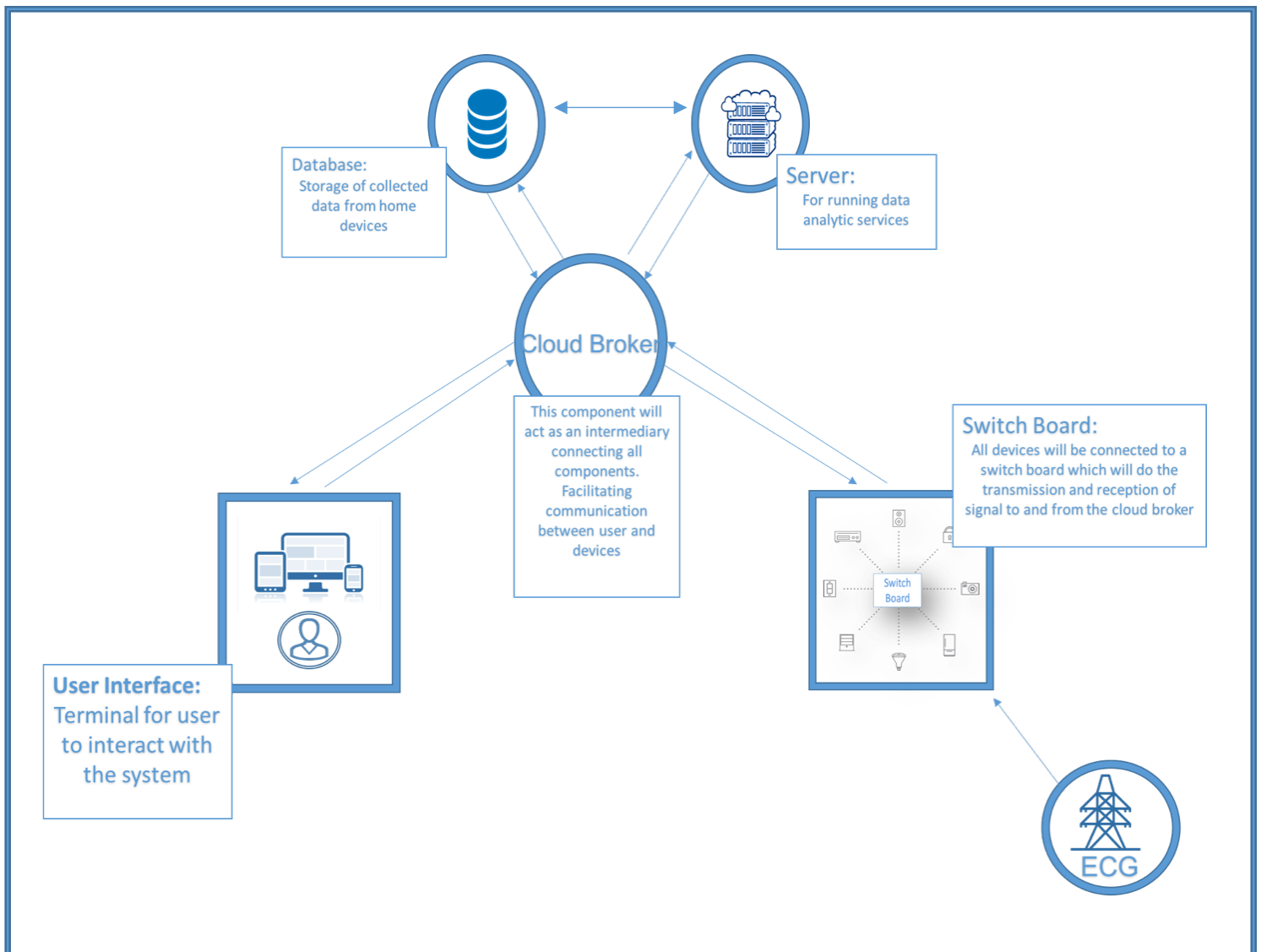


Figure 3.1: Context diagram of Ma Maison home automation system

Figure 3.1 describes the entire set of components of the Ma Maison System. It is made up of four communicating subsystems. These systems work together to make it possible for users to interact with system and achieve the intended purpose.

### **3.3 User Classes and Characteristics**

The main users of the system would be home owners and other inhabitants of the home. These two user groups would interact with the system at different levels of privileges.

- Home Owners – people who would be the main administrators of the system and usually the bread winner of the home. They will be required to log in to the system with a password to enable their privileges.
- Secondary users – these people are other inhabitants of the home who will interact with the system. This could range from children to adults, both literate and illiterate.

Looking at the two groups of users, it was imperative to make the user end of the application as friendly as possible to allow easy use and intuitive navigation throughout the system.

### **3.4 User Requirements**

User requirements were gathered through an open-interview with the target client. After the interview, requirement analysis was done to bring out the necessary requirements for the system as seen by the user and the developer.

#### **3.4.1 Functional Requirement**

The system's functionalities which were derived from the user requirements gathered were considered under two main categories, main functionalities and extra functionalities. The main functions will be the basic use cases that the users of the system require. The extra functionalities would be additional features that would be implemented to improve the system. From interviewing and studying the possible users of this system the following list of requirements were developed.

## **I. Monitor Electricity Consumption:**

### **a. Description and Priority**

This feature should enable the user to monitor electricity consumption of each individual appliance connected to the system. This should in turn give the overall electricity consumption of all appliances connected to Ma Maison. Users can monitor individual consumption of connected appliances. This is of high priority to the system since its results are integrated into several different areas of the project.

### **b. Stimulus/Response Sequences**

The user should be able to access Ma Maison via one of the user interfaces provided and should initially see total power consumption readings of all devices connected to Ma Maison on their dashboard. The user should then be able to select any appliance to view its individual electricity consumption reading.

### **c. Functional Requirements**

REQ-1: Users should be able to read electricity consumption of individual appliances as well as total electricity consumption.

REQ-2: Users should be able to see when each appliance was turned on and off.

## **II. Control Appliances in the home connected to the system:**

### **a. Description and Priority:**

This functionality should allow the user to control the devices in his home connected to the system at his/her finger tips. This should entail automating the switching on and off of the device or manually or remotely via his/her user interface.

### **b. Stimulus/Response Sequences:**

The user should be able to access Ma Maison via a user interface either remotely (out of the home) or in the home via the control panel. The user should be able to see a switch indicating the status of all devices connected to the system. The user should be able to then toggle the switch to either turn on or off the device for which the switch is associated with.

c. Functional Requirements

REQ-1: The user should be able to remotely control any appliance connected to the system via a button on the user interface.

REQ-2: The user should be able to automate the switching on and off of certain appliances connected to the system.

### **III. Use infographics to present the information gathered to the user:**

a. Description and Priority:

Visual representation of data is an easy and effective way of transmitting information derived from collected data. This feature should allow the user to enjoy the ease of understanding the electricity consumption information collected by Ma Maison.

b. Stimulus/Response Sequences:

Once the user opens the Ma Maison system, he/she should have a view of the dashboard which should use visual representations to display collected statistics.

c. Functional Requirements

REQ-1: The system should display consumption readings using visual illustrations to make it easy for users to understand.

REQ-2: The user should be able to identify periods of high consumption from illustrations.



#### **IV. Threshold Setting:**

##### **a. Description and Priority:**

This feature should be a marker that will be placed by the user to indicate his/her electricity consumption limit for the day or month. This will be regarded as the threshold within which the user is happy with his/her consumption. Whenever consumption exceeds this threshold the user would be alerted.

##### **b. Stimulus/Response Sequences:**

Users should be able to set a desired threshold for this feature to take effect. This will involve setting a desired limit to the power consumed for a selected time period, which could be a day, week or month.

##### **c. Functional Requirements**

REQ-1: Users should be able to set a threshold for their electricity consumption, beyond which the system should take a preset action/ alert home owner.

#### **3.4.2. Extra Functionalities**

##### **V. Data Analytics and power saving plan recommendations:**

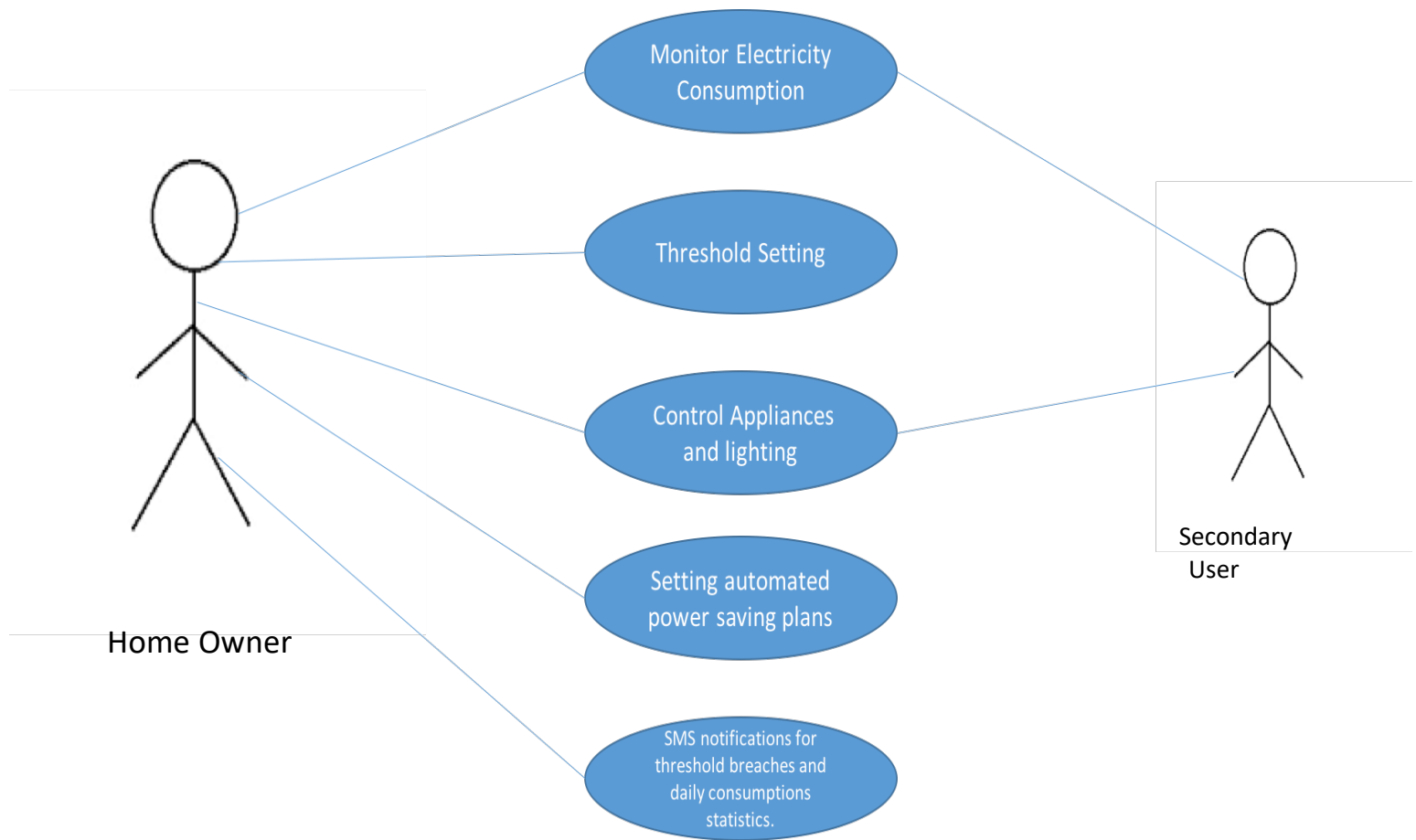
- a. The system should be capable of using data mining techniques to recommend a bespoke plan for each user that will automate control of appliances in order to cut down consumption without affecting the user's way of life.

##### **VI. Notification alerts on threshold breaches:**

- a. The user should be able to receive notification alerts in the form of email, SMS or push notifications indicating threshold breaches and daily consumption readings.

### **3.4.3. Non-Functional Requirements**

1. User-friendly Interface:
  - a. Considering the varying levels of technological knowledge that may exist in a home, the interface for the system should be intuitive in order to allow a varying users to interact with the system.
  - b. The interface should be simple enough to allow easy use and navigation.
2. Security:
  - a. The system should have a secure database to store sensitive information being collected about homes. The log-in information should be stored in either a hashed or encrypted manner in the database.
3. Internet connection:
  - a. For remote control of the home system, users need to interact over an internet connection.
4. Performance requirement:
  - a. The system should show very low latency in its execution of instructions sent from the user terminal.
5. High reliability & Availability:
  - a. The system should be up and running at all times and have very small down time.



**Figure 3.2: Use case diagram for different user classes and their privileges**

The Figure 3.2 shows the basic use cases of the system to different types of users. Primary users after verification should be able to access every functionality while secondary users should be limited to basic functionalities such as electricity monitoring and appliance control.

## Chapter 4: Architecture & Design

This chapter describes the architecture and design of the Ma Maison system. It details each component of the entire system and describes the function/role of that component in achieving the intended goal. The architecture used in this system is the client-server architecture.

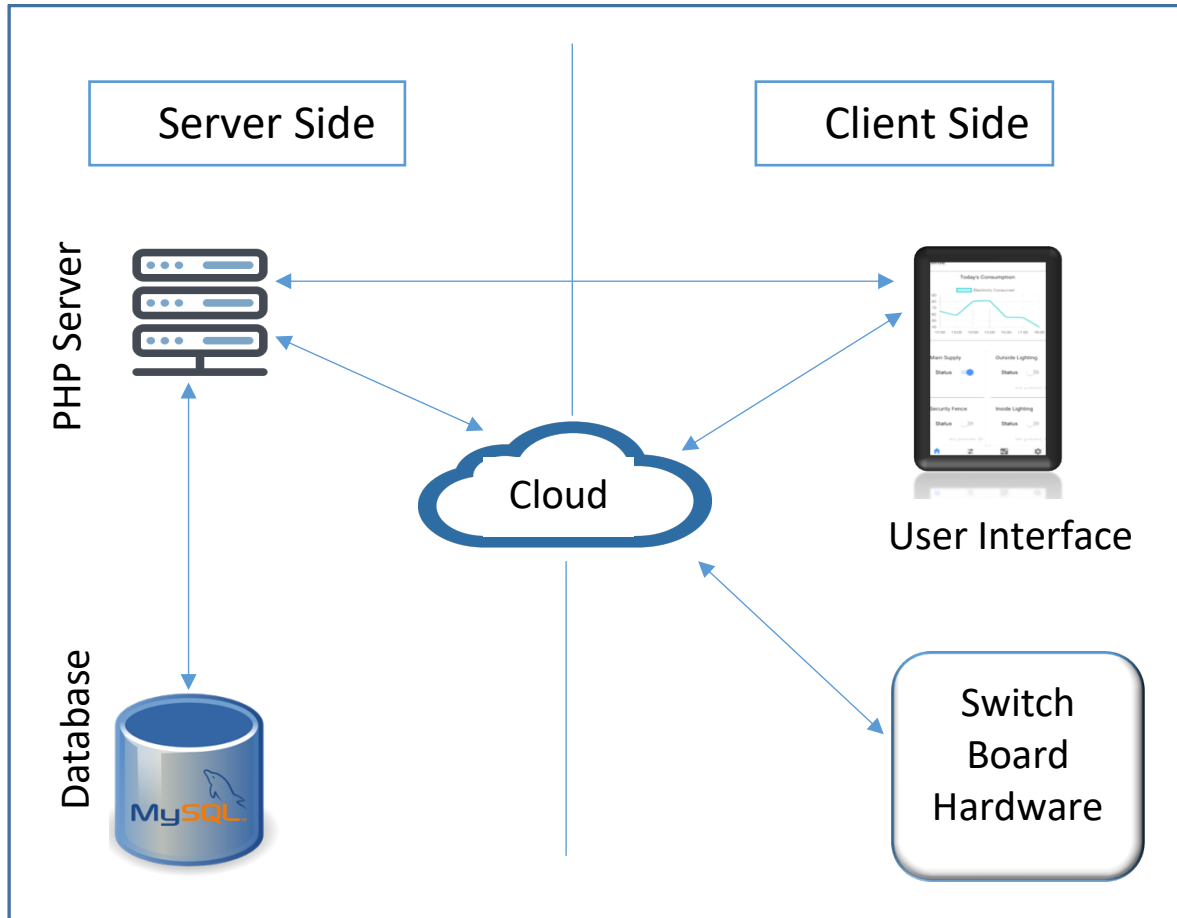


Figure 4.1: Client-Server architecture

### 4.1. Key Components in the Architecture

The figure 4.1 above shows the basic client-server architecture of the system. The server side components include the database and the PHP server. The PHP Server receives HTTP requests from the user interface to query the database for data. The PHP Server also receives data from the cloud broker to be inserted into the database. The client side components include the switch board and the user interface which both interact with the cloud broker. The cloud broker is left in the middle since it acts as both a server and a client depending on what function it is performing.

#### 4.1.1 IoT subsystem

This component is the system responsible for communication between devices connected in the system and the user's interface with the help of the cloud broker. The switchboard which will be running an MQTT protocol library and connecting to an MQTT broker over a network. The MQTT libraries are available for implementation in Java, C++, C or JavaScript. The device would need to have a TCP/IP stack which it could communicate via MQTT. In designing this system, the following design goals were considered;

- Low latency (speed)
- Low Power Consumption
- Low cost

In designing this system, two options were considered for the microcontroller, the Arduino Uno board and the Atmega 328p. To reach our design goal of a low cost, the Atmega 328p chip was selected. The Arduino Uno boards costs not less than \$30, while the Atmega 328p cost less than \$2. The Atmega 328p could provide an added benefit of efficiency and low latency if programmed in pure C language.

Another important component vital to the entire system was the communication module. The communication module is the component that provides internet connectivity to the board. Two modules were in consideration, the Wi-Fi module and the GSM module. As a result of restrictions on the available Wi-Fi network (Ashesi Air), the cheaper alternative which is the Wi-Fi module was not suitable. Hence, the GSM module was chosen to be used to develop the system. This module would allow the system to connect to the internet anywhere with carrier coverage.

The design schematic of the entire board was developed using an electronic design automation application called Eagle. Figure 4.2 shows the schematic of the circuit that was constructed. This schematic provided the blueprint for connection and wiring of the board.

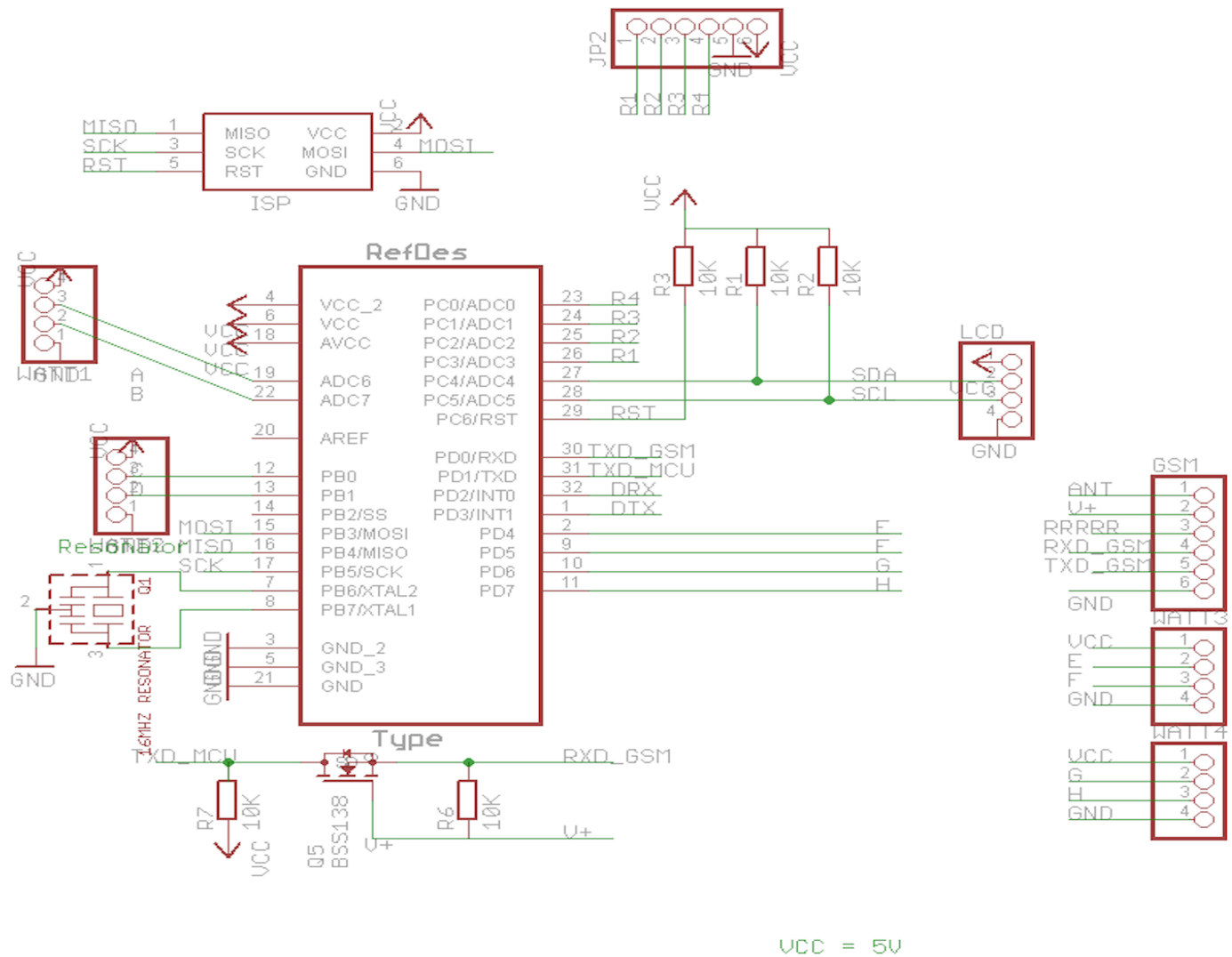


Figure 4.2 : Switch board schematic

#### 4.1.2 Cloud Broker

This component of the system serves as an intermediary between all the subsystems. It is responsible for receiving all messages published to it and directing them to interested subscribed clients (users). It will interact with the mobile application and also with the server. This component will communicate to all the other components connected to it using the MQTT protocol.

#### 4.1.3 Server and Database

These two will form the back-end of the entire system and will be responsible for data storage and relay between database and other components such as cloud broker and mobile application. The server side will serve two main functions, the first of which would be to interface between the

mobile application and the database. It will be a PHP server which will relay information between components. The Appendix B contains PHP scripts loaded onto the servers. The database would be a MySQL database system organized as a relational database. It will have information pertaining to each appliance and its metered readings.

#### 4.1.3.1 Data Model

The data model that would be used to keep the information collected about electricity consumption and devices connected to the system is shown in the entity relational diagram in Figure 4.3. The entity relation diagram helps show the significant structure of the data model.

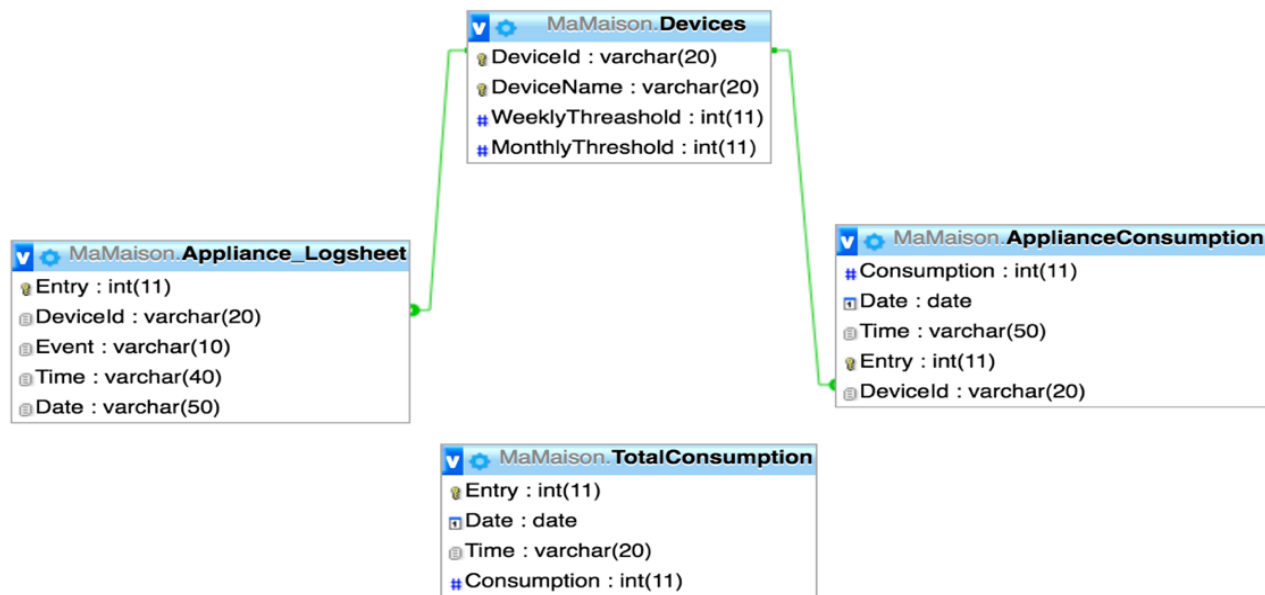


Figure 4.3: Entity relation diagram for collected data

#### 4.1.4 User Interface

The user interface is a very important component which would determine the user's experience with the entire system. The system will have a mobile application which the users will use to interact with the system. This mobile app will interact with the cloud broker over MQTT to retrieve and send information to the hardware. It will also communicate with the PHP server over

HTTP to retrieve historical data from the MySQL database. It will use firebase for log-in authentication as shown in the figure 4.5. This user interface would need to be designed in a responsive manner considering the different devices going to be used to access the interface. Figure 4.4 shows mock presentations of the interface design for the home page, which are yet to be implemented. The design makes it easy to view the current consumption and also control appliances using the toggle buttons. The third image in the figure shows the interface on the user terminal where historical data can be accessed. This data will be show in the form of block, line and pie charts. Figure 4.5 shows activities involved with authenticating a user in order to display homepage. For security purposes log-in is required before access is granted to the app.

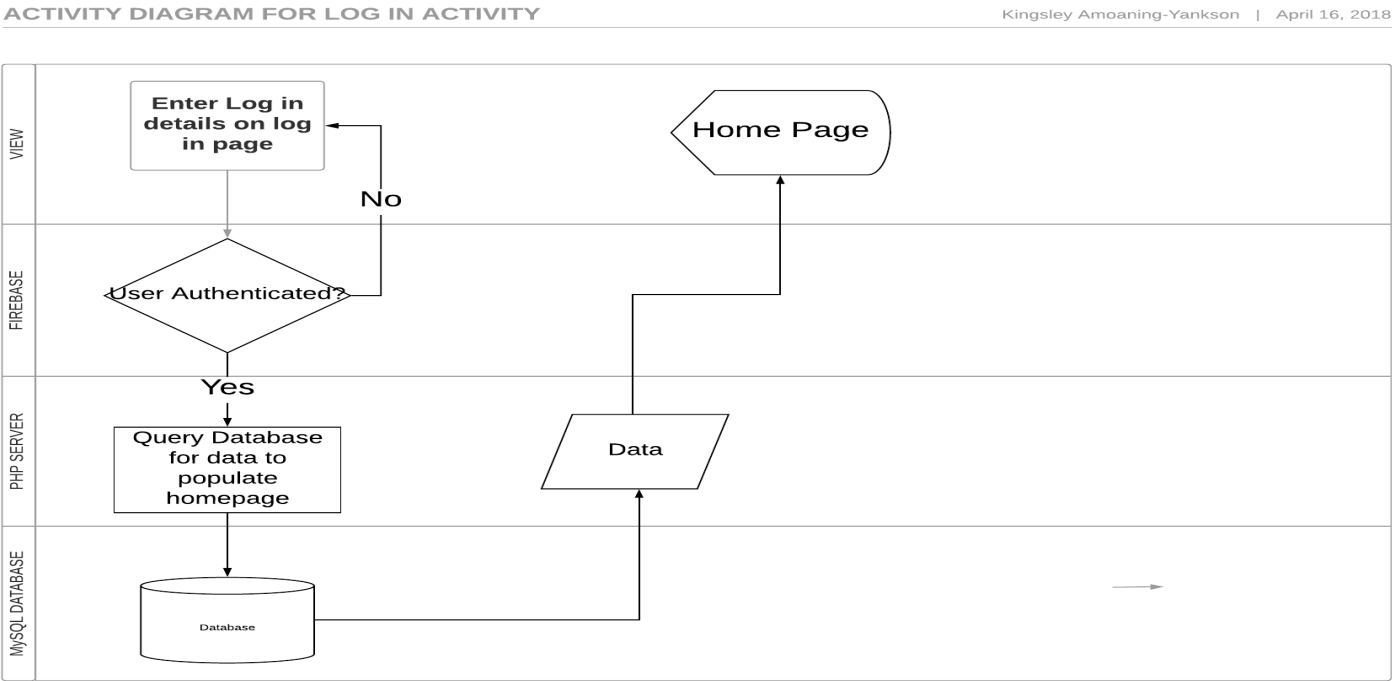


Figure 4.5: Activity flow diagram for log in process

4.2 Operating Environment

The system is made up of different components that all need to communicate effectively. The system will be very dependent on a messaging protocol for the IoT component of the system. This subcomponent will require understanding of the protocol to be used, as well as its pitfalls. The user interface subcomponent will be developed using web technologies such as html, CSS,



JavaScript and PHP for the server side programming. MQTT would be used to communicate with the cloud broker.

The Figure 4.6 illustrates the protocols used in communication between the different components of the system. The user interface communicates with the server over HTTP (Hyper Text Transfer Protocol) and receives data in the form of JSON (JavaScript Object Notation). All other communicating components, except the database, work via MQTT. Messages are published to a particular topic on a central cloud system, which then distributes the messages to all subscribed components.

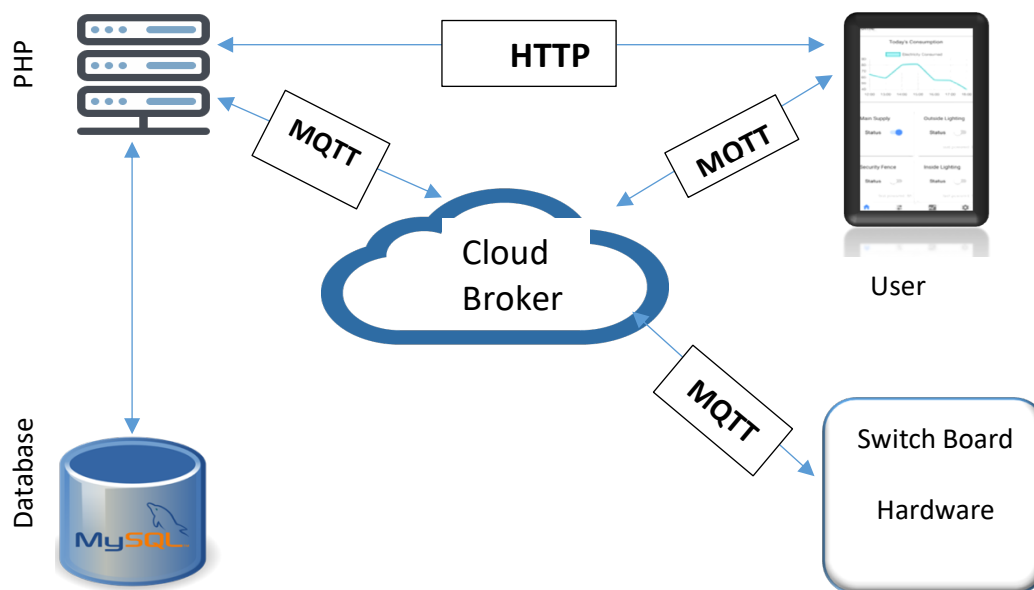


Figure 4.6: Protocol communication architecture

### 4.3 Design and Implementation Constraints

There exists a significant number of constraints that affect the development of this system. The system will be dependent on an internet connection in order to allow remote (out of the home) communication between user and Ma Maison. The components of the system should be such that they do not consume significant energy which would also lead to an increase in electricity consumption.

## **4.4 Assumptions and Dependencies**

### **4.4.1 Hardware dependencies**

All appliances within the system would be connected to a switchboard which in turn serves as the transmitting and reception mechanism for signals being sent and received from users.

### **4.4.2 Time Dependencies**

As a result of the time constraints and the possibility of a broad scope of functionalities that could be integrated into this system, prioritization is necessary. For this reason, the main features of the system would be developed before the extra features described earlier would be added on.

## Chapter 5: Implementation

This chapter provides a detailed description of the processes used in the implementation of the Ma Maison Home Automation System. The chapter touches on 3 major areas; the actual development of the front-end application, communicating hardware and data collection engine. For each subsection, the libraries and technologies used are brought to light. The client-server architecture was used in the development of the system.

### 5.1. Overview

The Figure 5.1 shows a detailed architectural diagram of the entire Ma Maison system. It shows the user terminal being used to do two things; send instructions to the cloud broker via MQTT and sending HTTP requests to the PHP server to retrieve data from the database for the construction of its graphs and charts. The GSM module provides the microcontroller with the ability to connect to the cloud broker to receive instructions sent from the user terminal and to publish electricity consumption values based on readings from the PZEM-004T modules. After processing instructions received from the broker, the microcontroller uses the relays to cut power going to a target appliance connected to the system. The LCD screen is used to display messages and readings from the microcontroller directly on the board.

The client-server architecture was chosen to be implemented for two main reasons, scalability and access control. This architecture allows us to increase the number of clients and server separately without causing any problem to the system. The PHP server used to access the database serves as an access control helping protect data integrity and preventing malicious access to historical data. Also the client-server architecture has several developed technologies that can help provide security of transactions and ease of use.

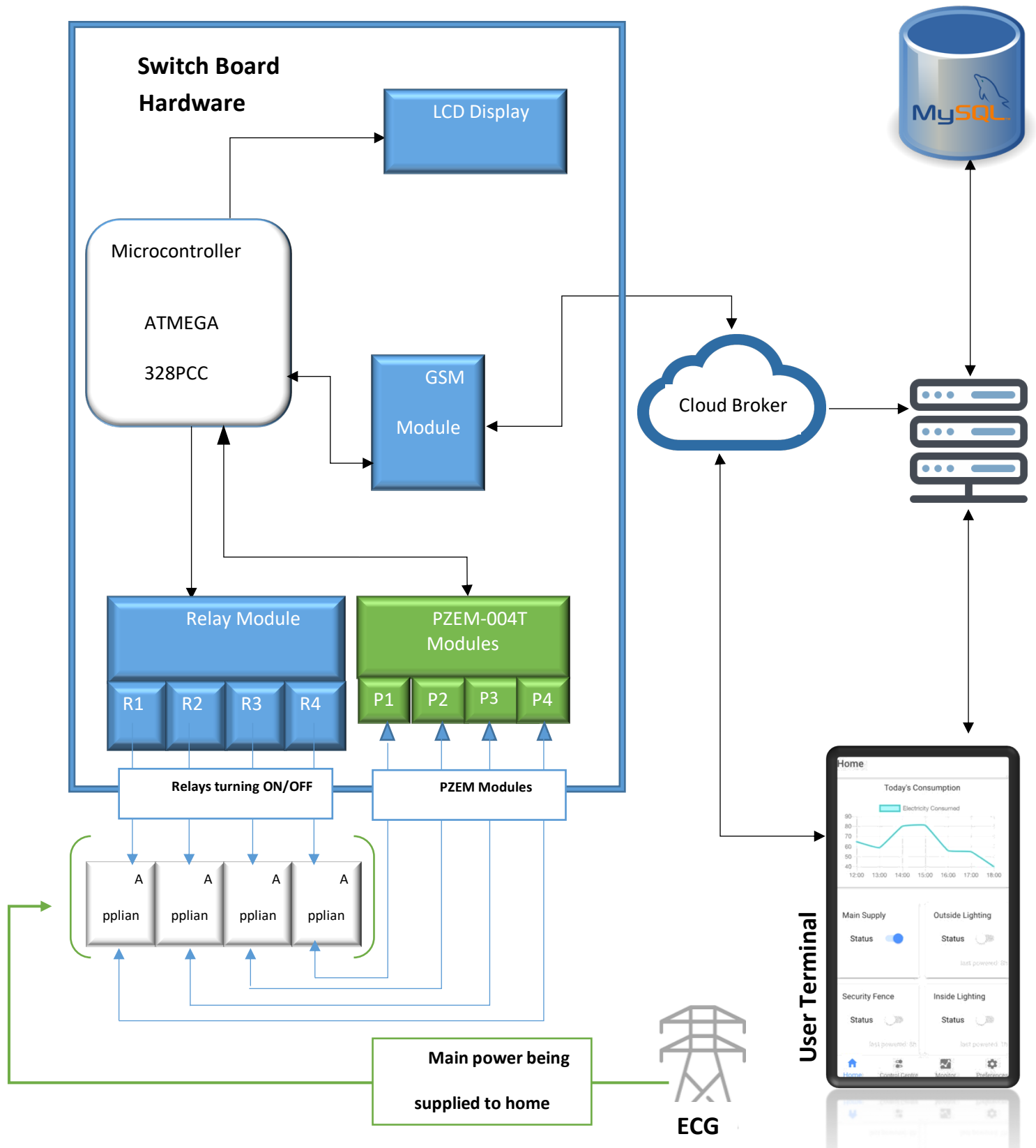


Figure 5.1 : Overall system architecture

## 5.2 Front-End Application

### 5.2.1 User Interface

The front-end application is the main portal with which users can interact with the system to control their home appliances and help monitor their electricity consumption. Due to the complexity of the different communicating components, this user-interfacing component requires a very user friendly and intuitive interface.

Below are some images of the user interface. The first image in figure 5.2 from the left is the home screen which shows the electricity consumption data and live readings in a graph as well as in number form. It also has switches that control the most important or frequently used appliance. The second image is the control center where users get to control or add on new appliances which they connect to the system. The last image which is referred to as the monitor, is used to display the historical data collected over time by the system and shows different graphs and means for users to better understand their electricity consumption.

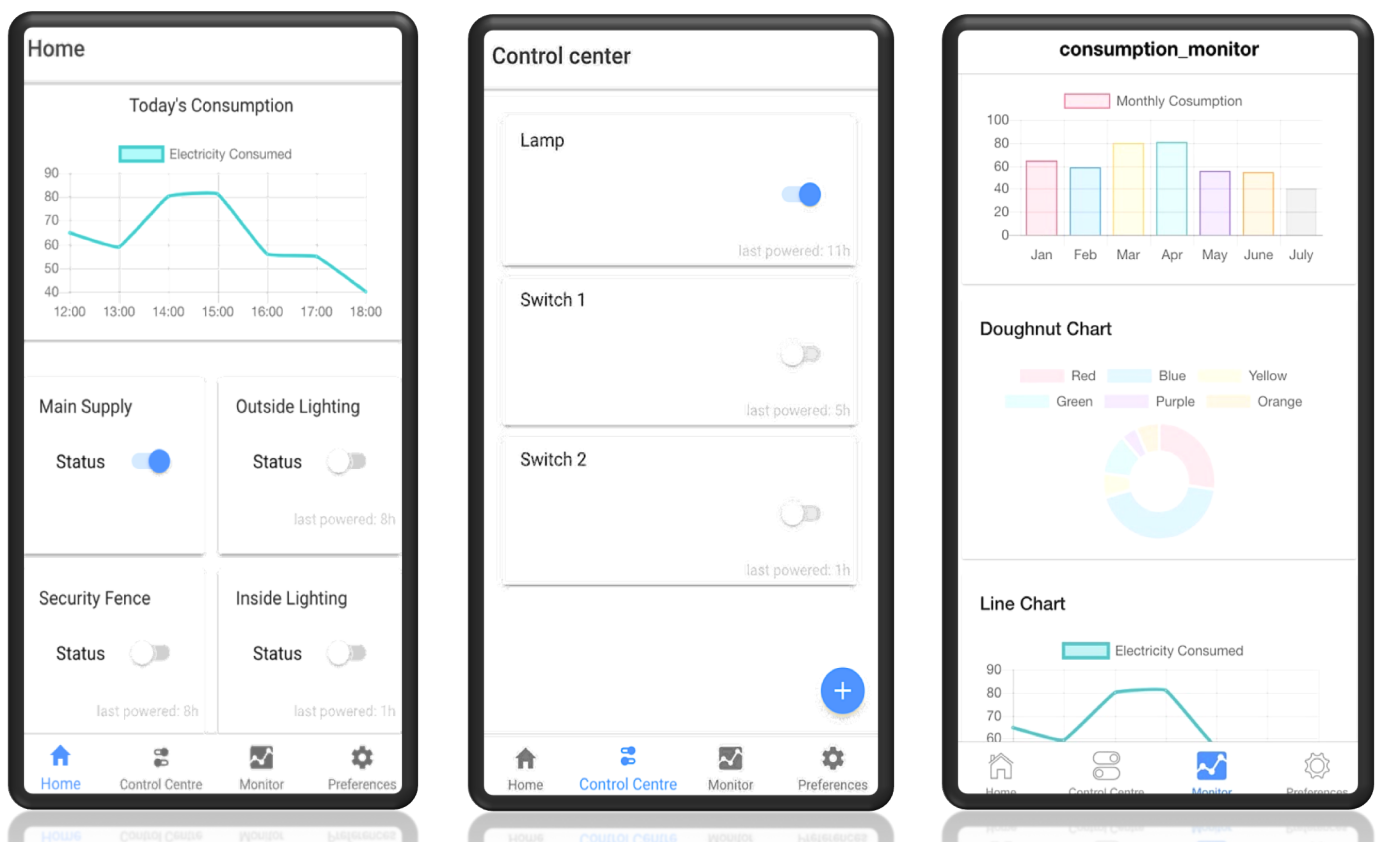


Figure 5.2 : User interface application

### 5.2.2 Development

The application was developed using the Ionic framework which is an open-source tool for creating hybrid mobile applications. Technologies used in development were TypeScript, Angular JS, HTML, CSS, Java Script and SCSS. This platform allows you to develop one application for multiple platforms (web, Android, and IOS). The HTML used is a markup language used to create the actual interface and elements of the interface. The Cascading Style Sheet (CSS) and its super set (SCSS) help style the HTML elements to produce the desired look and interaction for the user. The remaining technologies such as TypeScript, Angular JS and JavaScript did the heavy lift of the application which involved carrying out actual functionalities and communication with other components of the system. Libraries such as Chart.js and MQTT.js were leveraged in the implementation of certain features.

### 5.3 Switchboard (Embedded System)

The switchboard is the main sensing and communicating component that interfaces between the actual home appliances and the cloud broker. It deals with reading the power consumption of appliances connected to it, as well as receiving instructions to turn them on or off from the user's terminal from the cloud broker. It is made up of several electronic hardware that will be discussed in the subsequent paragraphs.

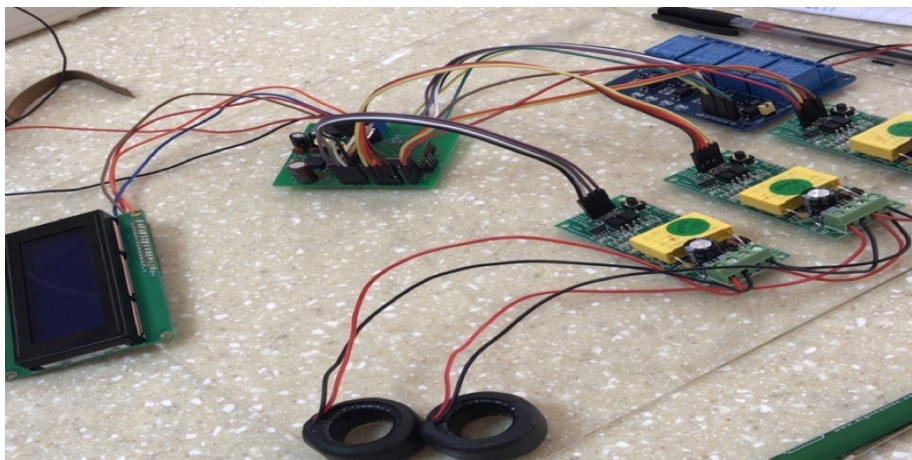


Figure 5.3 : Assembled switchboard

### 5.3.1 Printed Circuit Board

This printed circuit board was designed using a software called Eagle. The printed circuit board (PCB) holds the electronic circuit together. Mounted on the PCB shown in Figure 5.4 are components such as an Atmega 328/P microcontroller, a buck-converter, a SIM800L GSM module and BSS138 mosFET. All these components are connected using conductive paths which are routed by the Eagle software. The subsequent paragraphs will highlight the most important components that were mounted on the PCB and a summary of how all the components work together to achieve the intended goal of the PCB.

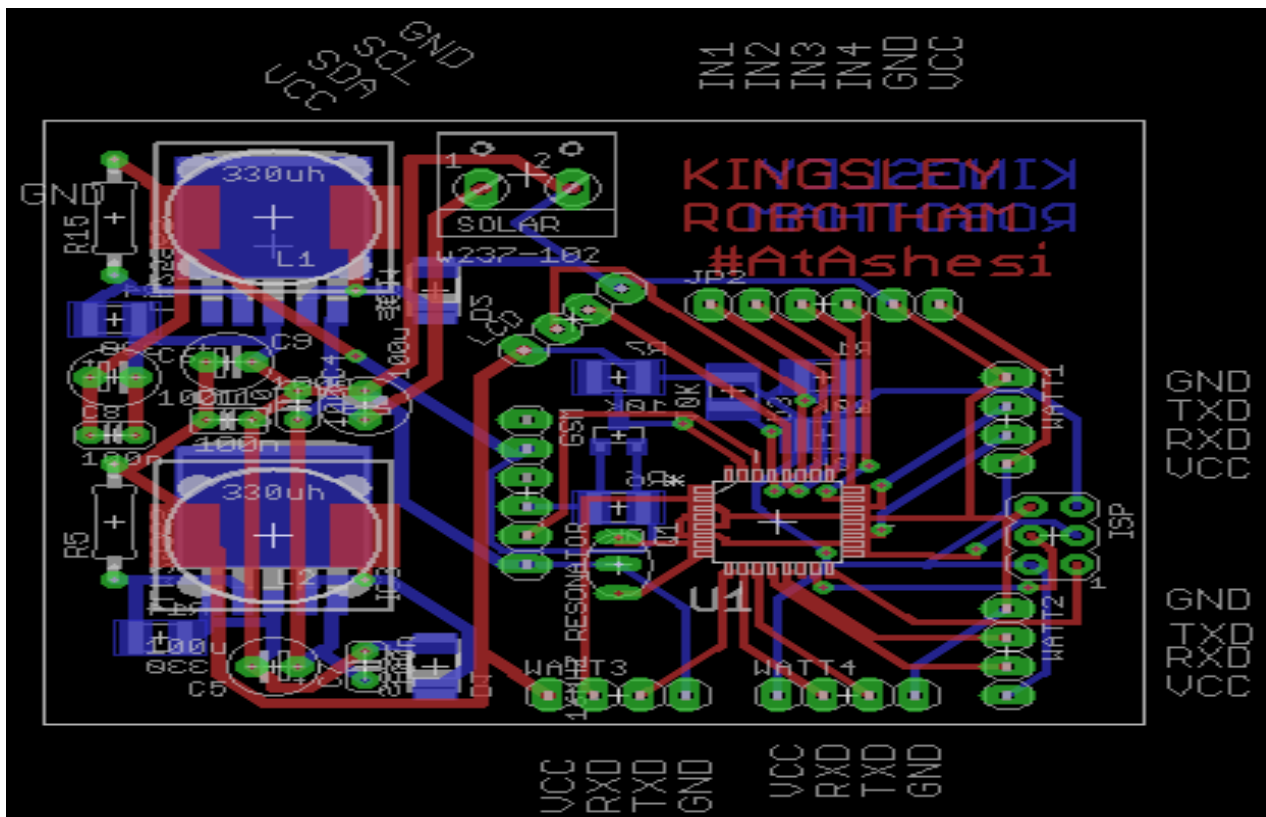
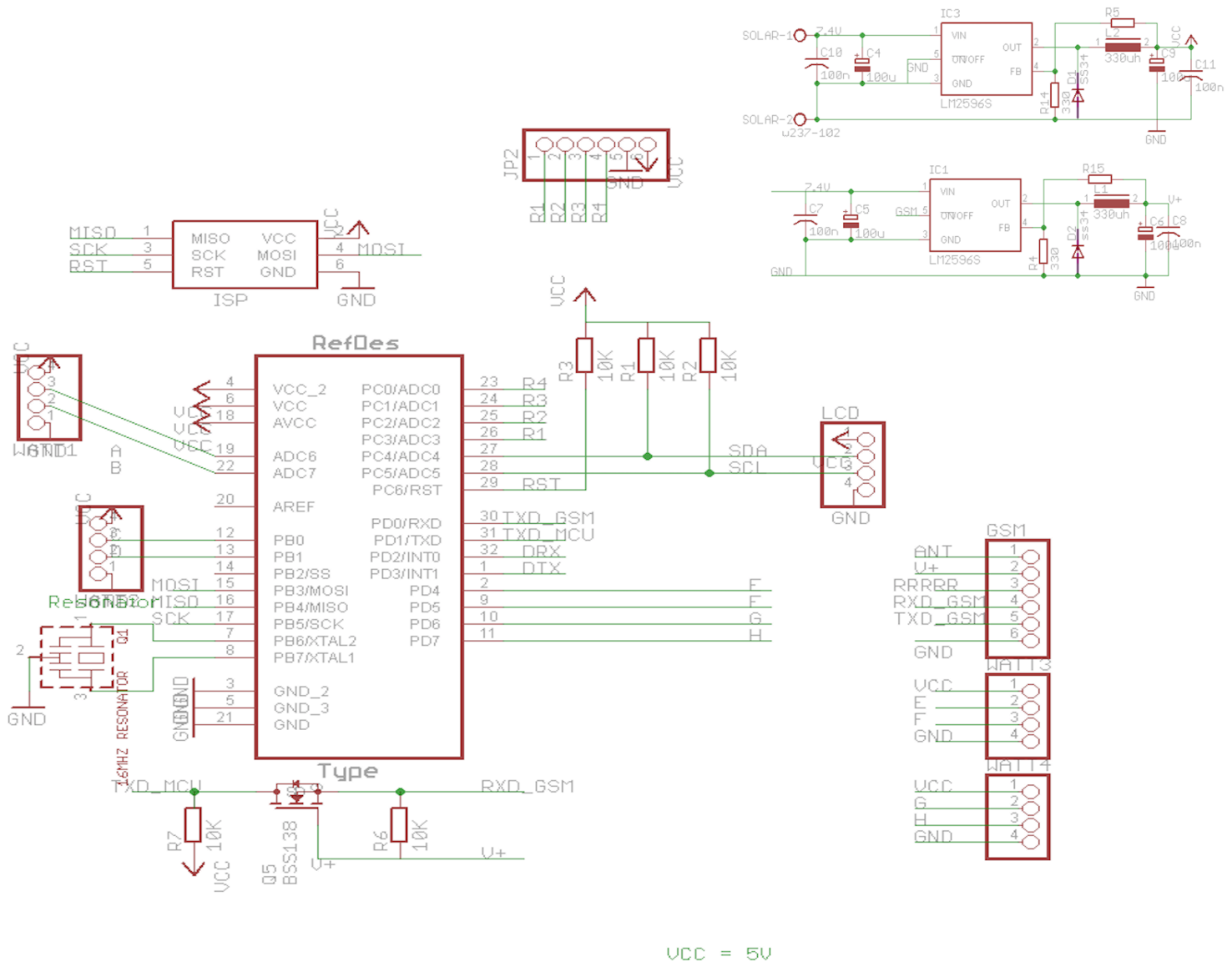
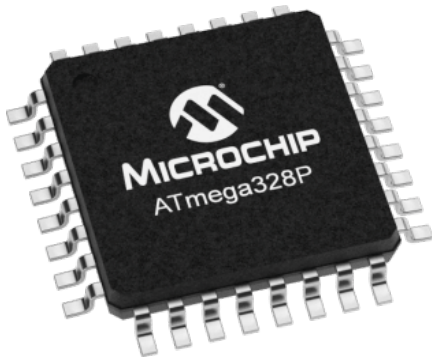


Figure 5.4: Printed circuit board





from the cloud broker, calculate electricity consumption values based on readings provided by the PZEM-004T modules and send calculations to the cloud broker. The Arduino sketch enables the microcontroller to connect to the cloud broker and communicate over MQTT. Appendix A contains Arduino sketches used to program the microcontroller for the system. The Figure 5.6 shows the surface module version of the ATmega328/P



**Figure 5.6: Microcontroller atmega 328/P**

### **5.3.1.2 Important Pull-Up Resistors in the Circuit**

On the PCB board were three 10k ohm resistors. A resistor is an electrical component that provides resistance to the flow of current thereby reducing the current of flow in a circuit. The two resistors were used as pull-up resistors connected to the Inter-integrated circuit (I2C) which interfaced with the LCD screen. The second pull up resistor was used to set up a connection for a reset. The pull-up resistors were used to initialize general input/output pins to a default state that can allow them to be used. Referring to the Figure 5.5 resistors R1, R2, and R3 were used as pull up resistors. R1 and R2 were used to pull up the I<sup>2</sup>C bus, namely the serial data line (SDA) and serial clock line (SCL). R3 was used as a pull up reset pin for the microcontroller high so that any low pulse of up to one clock cycle could reset it.

### 5.3.1.3 SIM800L GSM module

This is a miniature board that is capable of providing a GPRS/GSM network to the microcontroller which is connected to it. An MTN sim card was inserted into this module and connected on the system. It gave the microcontroller the ability to connect to the internet and transmit as well as receive messages over it. It works with both 2G and 3G access technology providing some form of redundancy and robustness.

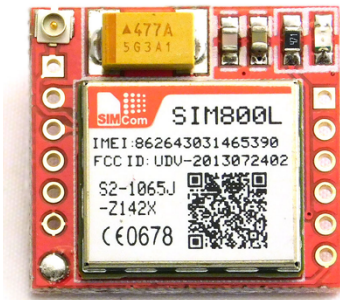


Figure 5.7 : GSM module

### 5.3.1.4 PZEM-004T Modules and Current transformers

This component is an electric monitoring and communicating device which is used to monitor voltage, current and power, passing through any cable passing through the coil of wire which is the transformer. This component provides values with which the Arduino code loaded onto the microcontroller uses to compute the electricity consumption of the connected appliance.



PZEM-004T



CURRENT

Figure 5.8 : PZEM-004T module

### 5.3.1.5 Liquid Crystal Display (LCD)

The Liquid Crystal Display (LCD) has been used in this project to output readings obtained from the PZEM modules on the board. It is used as the output display for the microcontroller, and allows the microcontroller display messages directly on the board. As shown in Figure 5.4 the LCD is connected to a four-pin terminal block which is connected to the I<sup>2</sup>C bus.



Figure 5.9 : Liquid Crystal Display

### 5.3.1.6 Relays

A relay is an electronic device which is used to break an electrical circuit, temporarily stopping current from moving through circuit. It is used as a switch to control the electricity flowing through the circuit (Sinha 2014). The relays were used as switches controlling the flow of current to the connected appliance. As shown in Figure 5.4, the relay module is connected to the JP2 terminal block and the nets corresponding to the relays are named R1-R6.

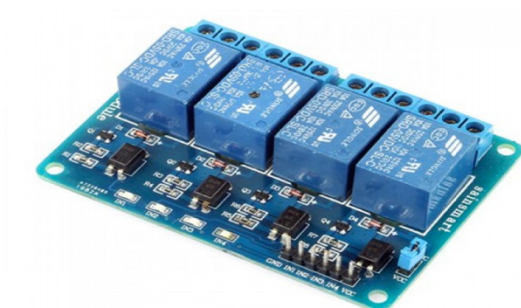


Figure 5.10 : Relay module

### 5.3.2 Component Integration and Functioning

All components mentioned above were combined to build the switchboard, which involves soldering of different components onto the PCB and wiring each component following the Atmega 328p microcontroller's pin out data sheet. The development and testing of this board was done with caution and with the risk of electrocution in mind.

The brain, as mentioned earlier, is the Microcontroller Atmega 328/P, which was the main programmable component. It was programmed using Arduino to connect to the mosquito test server (cloud broker) via the GSM MQTT library. However, the GSM module and the microcontroller work on different communication logic levels. Hence, there was a need for logic level conversion between the GSM module and the microcontroller. Resistor R6 and R7 together with the BSS138 were used to create a logic level convertor, which was used to achieve the logic level conversion between the GSM module and the microcontroller.

One major role of the hardware was to provide the functionality of turning off/on appliances connected to it. In order to achieve this, appliances were wired through the relay module which could be controlled by the microcontroller to break or connect the electronic circuit, thereby turning off/on the appliance. The microcontroller was able to connect to the internet with the help of the GSM module. The internet connection allows the microcontroller to receive messages published to topics (Topic for the lamp: King/MaMaison/Light/Event) it is subscribed to in order to retrieve instructions. As seen in Figure 5.11, when the switch board receives instructions to turn on/off an appliance it triggers the relay module to either close the circuit or open the circuit to achieve the intended instruction. When the circuit is closed the lamp is powered and once the circuit is opened it is turned off. Figure 5.11 illustrates the flow of instruction from the user terminal down to the connected target appliance.

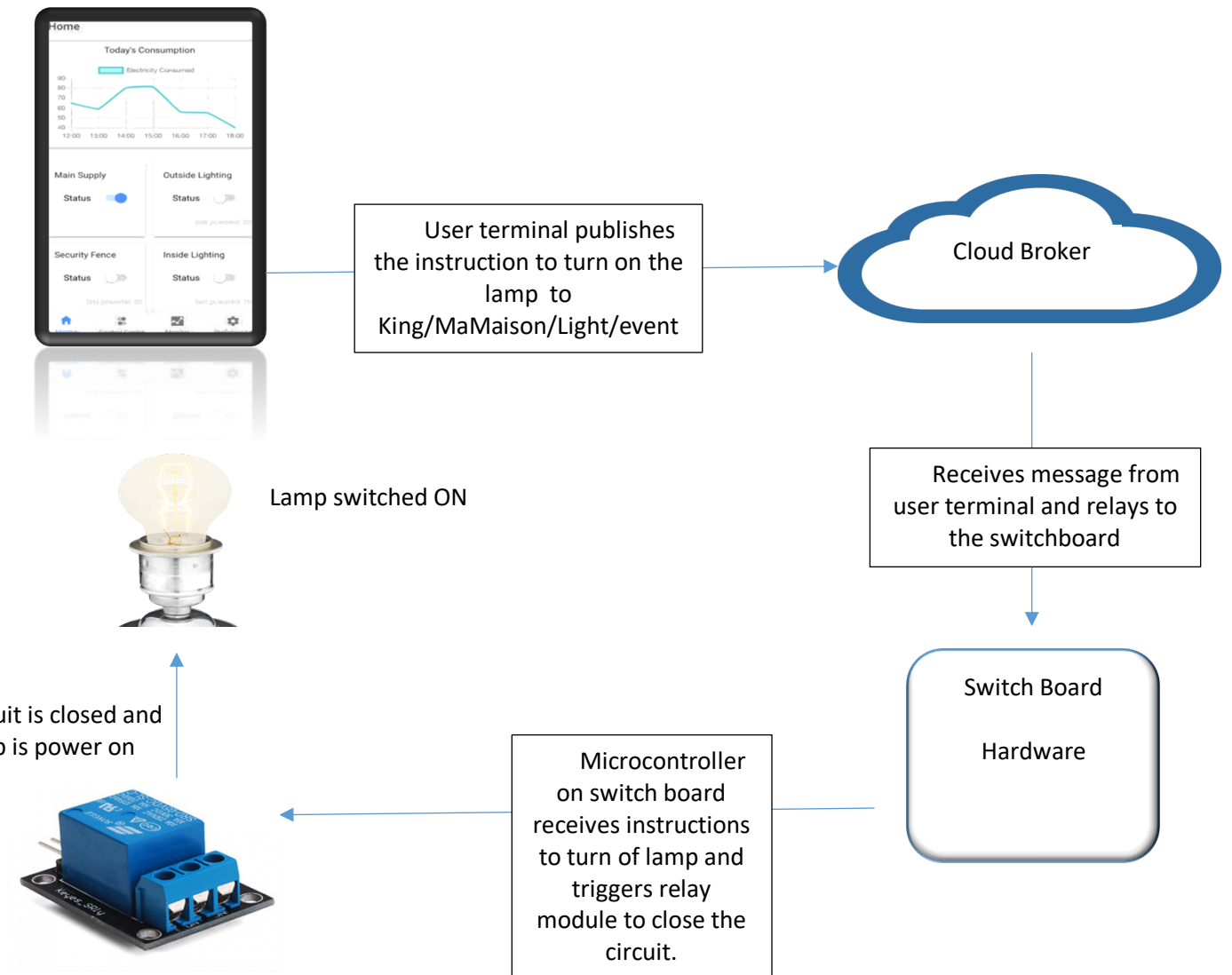
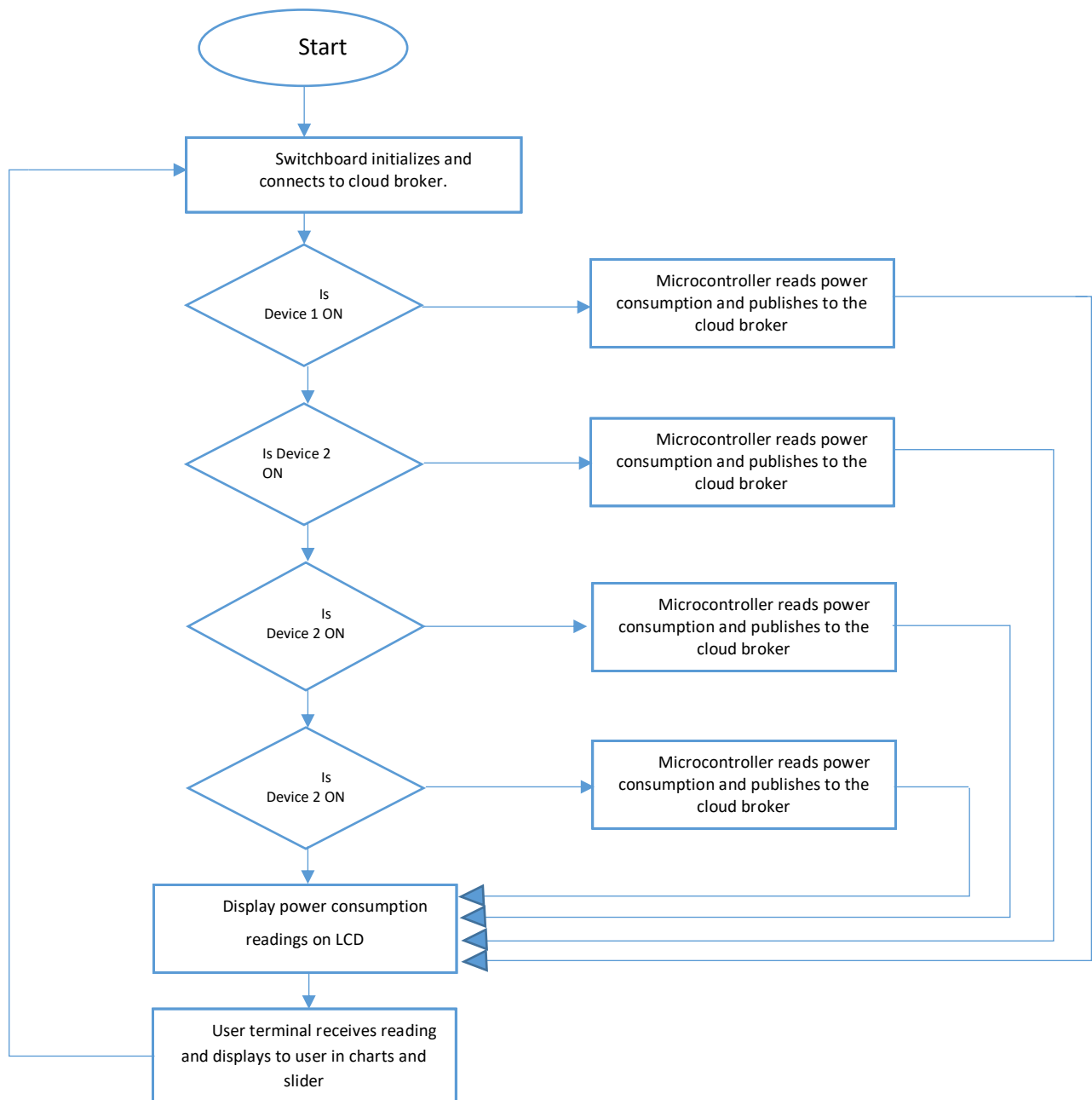


Figure 5.11 : Flow Chart : Remote Appliance Control

Another function of the board was to calculate electricity consumption and publish it to the cloud broker. To achieve this function the power cables providing each appliance with power was passed through a current transformer connected to the PZEM-004T module. This module can read voltage or current flowing through the cable and convert that information into a form that can be used by the microcontroller. The microcontroller computes the electricity consumption and publishes it to the cloud with the help of the GSM module and MQTT. The Figure 5.12 summarizes the sequence of events that make this functionality possible.



**Figure 5.17 : Flow-chart for consumption reading**

## 5.4 Cloud Broker

For the cloud broker, a test server provided by Eclipse at the address [test.mosquitto.org](http://test.mosquitto.org) is used. This service provided a managed MQTT broker implemented from the Mosquitto MQTT module. It is a free cloud-based service that allows users to make use of a public test server without having to bother about hardware or software maintenance. This service allows web socket connection and also, TCP connections to the broker allowing it to be accessed via browser and any other means. The desired service would have been a paid cloud service account with Cloudmqtt.

This account generates a password and designated username with which MQTT clients can connect to, via the stipulated web address. It presents a much better service and reliability as compared to the mosquito test server.

## **5.5 Summary of Implementation**

Security is one of the major issues associated with IoT applications. This project tries to mitigate the access to the system by providing certain key features such as access control. The user terminal can only be accessed after user details are authenticated, in order to reduce chances of malicious access. Data transmitted over the network via the MQTT protocol is encrypted to make it less easy to hack. The switchboard will be placed in a secure place in the user's home to reduce the chances of physical attacks to the system.

This chapter focused on the different subsystems of the entire Ma Maison system and how each subsystem was implemented. Detailed descriptions and functions about each subsystem were provided. The next chapter will cover the testing of the entire Ma Maison system providing criteria of acceptance and testing techniques used.

## **Chapter 6: Testing & Results**

The chapter encapsulates various testing methods employed in ensuring the working functionality of the Ma Maison system.

### **6.1. Testing Approach Description.**

Considering the system is made up of several communicating components which interact to make the purpose of the entire system possible, it is undoubtedly important to test that each individual component works appropriately on its own. Once this was achieved, integration testing took place to ensure components work adequately with each other, serving their intended purpose. User testing was conducted to identify the user's interaction with the system. The prevalent criteria considered throughout testing were:

- Latency of the system
- Responsiveness
- Correctness

### **6.2. Unit/Component Testing**

#### **6.2.1. Switchboard**

In testing the switch board component, a bulb was used as the connected appliance throughout. The following tests were conducted using the criteria mentioned above;

- The switchboard hardware was tested to ensure it was reading the correct voltages and current consumed by appliances. This was done by comparing values produced from the hardware to power reading produced from a multi-meter. This test was intended to check the correctness of the system. The Table 6.1 shows results of voltage readings made by the switchboard and readings made using the multi-meter. Difference in voltage readings were very small and negligible.



**Table 6.1. Voltage reading test results**

Test	Ma Maison Results (Volts)	Actual Results (Volts)
Reading 1	• 234	• 234
Reading 2	• 233	• 235
Reading 3	• 230	• 231

- The next test conducted on the switchboard was directed at testing the board's ability to control power going to different appliances as well as the latency involved with that action. This was done by connecting all relays to different light bulbs and attempting to turn off/on each bulb by controlling the relays programmatically in Arduino code. In order to compare timing, a simple circuit was setup with 2 bulbs and two switches to control each bulb. This test was to prove the possible responsiveness the system could have as compared to the manual process which existed. The test involved recording the number of times each setup could turn on and off all its bulbs within thirty seconds. An observation made with the switchboard was that the switch happened so fast, it was difficult to keep count manually. It was better to set up a counter variable to programmatically keep count of each time the lamp was turned on and off. The results as shown in table 6.2 prove that the switchboard is more responsive and has a lower latency as compared to the manual process. Manual process as mentioned earlier entailed an actual circuit set up with two switches. A tester was then timed to go between

**Table 6.2: Test results - counts per 30 seconds**

Test	Ma Maison Switchboard	Manual Setup
1	• 130	• 64
2	• 134	• 60
3	• 140	• 69

### 6.2.2 Cloud Broker

The first test conducted on this component was intended to check latency. Essentially how long it took the component to receive messages published to it and relay it to the appropriate end terminal. An average Two different end terminals were considered in the testing, mobile application and PHP server. The results of this test may vary if replicated as a result of internet speeds in different coverage zones. As the results table shows differences in the average timings for accomplishing each task. However these differences were as a result of network connectivity and the internet.

**Table 6.3: Cloud broker test results**

Test string sent	Switchboard to Cloud to Mobile App (seconds)	Switchboard to Cloud to PHP server to Database (seconds)
“50”	• 00.23	• 2.00
“Ma Maison is up”	• 00.30	• 2.15
“2000000000000000”	• 00.24	• 2.01

### 6.2.3 User Interface - Ionic App

The user terminal which has been developed in the ionic framework has been tested with the use of process and stage logging to console as well as test functions. White box testing was employed to ensure the component’s internal design and structures were considered during testing. This component was tested to ensure it is capable of sending instructions to the cloud broker on specific topics.

The system was also tested by cutting the internet connection to the phone while receiving live updates from the cloud broker and trying to control an appliance. The prior activity did not face any adverse effect on the system except the inability of certain fields to update. Sometimes, the appliance control would sometime turn off/on, the appliance with no feed back to the user terminal or would not carry out the intended action at all.

### 6.3 System Testing

The system was tested in two main ways which involved all the components of the system working together. The first task was turning on/off an appliance connected to the system. This involved sending instructions via the button switches in the mobile app to turn off/on a particular appliance. This task was timed to measure the latency and responsiveness of the system. The Figure 6.4 shows the results of the test. Results tell how much time it took to turn on the listed appliances from the user's terminal. Each time entry is an average of three instances. These results show that the system is responsive and displays a level of accepted latency. The Appendix C contains images from system testing.

**Table 6.4: Appliance control times**

Test	Switching of Appliance (seconds)
Lamp	• 00.23
Switch1	• 00.30
Switch 2	• 00.24

The next test was done to check the correctness of the entire system. This was done by comparing the electricity consumption readings displayed on the switchboard's LCD to what was eventually entered into the database with the help of the PHP server as well as how long it took to do the database entry. Appendix C show sample readings shown on the switchboard's LCD. The Figure 6.5 shows how long it takes the system from reading the appliance to making an entry into the database. Each entry is an average of three attempts.

**Table 6.5: Time taken from switchboard to database**

Test	Database recording of reading from switchboard (seconds)
1	• 2.00
2	• 1.45
3	• 2.01

The system was also tested to see how it would recover from a power cut. The power being supplied to the board was abruptly stopped while the board was functioning. This resulted in loss of any ongoing calculation and possible duplication of readings being sent to the cloud.

## **6.4 User Testing**

Testing in this area was done to ascertain the appropriate human interaction with the system and ensure the system met user requirement. The first test, involved installing the user terminal (mobile app) on different android models to see how the app looks on different models. Installation was done on new generation android phones such as the Samsung S7, S8 and Note 7. As well as older models such as the Samsung A7, S3, and S4. The observation made from the test was that the newer models showed very crystal clear graphics and quick transitions between activities. Whereas the older versions also managed to display the user interface fairly well with some color distortion and a few icon changes. However, the Samsung S3, demonstrated slow transitioning between pages.

The next test involved observing users who had been given the chance to interact with the system learn to use it without any directions. Users were told the purpose of the app, but not given any further information. This was to test the intuitive nature of the interface. Users were able to successfully turn off and on appliances connected to the system and also make meaning from the visual representation of the data.

## **Chapter 7: Limitations, Future Work & Conclusion**

### **7.1 Limitations**

After researching into existing solutions in the Ghanaian market, one of the major problems preventing people from adopting similar technologies was the intrusive nature of the installation of similar systems. In order for the Ma Maison Home Automation System to overcome this hurdle, it needed to present a solution which would not be as intrusive as the others in the market. However, this would require purchasing several radio frequency modules which would spike the cost of the project, and hence why a wired approach was used in implementation.

Another limitation which affected the high availability of this was the purchasing of a cloud broker service which would provide a much more secure server and reliable service as compared to the test server provided by Mosquito Eclipse being used. Purchasing an account with CloudMqtt would help provide this needed feature once the system is ready to move out of the development and testing stages.

The switch board component of the entire system is able to connect to the internet through the GSM module, which uses cellular connection. In the instance of areas where cellular network is unavailable, the system will not be able to function. Redundant hardware such as a Wi-Fi or Ethernet module could be mounted on the board as a secondary source of internet connectivity in the instance where the GSM module is not able to receive cellular service.

### **7.2 Future Work**

The project in its current state provides a foundation for more interesting and useful improvements to be added. One of the additional functionalities stated but not implemented was the data analytics and power saving plan recommendation generator. This could be made possible with the use of machine learning, which is capable of learning user's habits and preferences and

automating control of appliances as well as recommend tailored power saving settings for the user's home.

The complete certification of this project would include actual field testing which can be carried out in the future of the project. Installation of the system in an actual home for a period of at least a month, would help verify its actual ability to aid in the reduction of electricity consumption in homes.

The system could also be extended to incorporate more home automation functionalities such as CCTV monitoring, automated door locks, and temperature control to make the system look more wholesome and attractive to a wider range of audiences.

The project can be further extended to incorporate the use of Radio Frequency modules which can be attached to every appliance. This component would make it possible to communicate reading from appliances anywhere to the switch board over radio frequency. This would overcome the need for intrusive implementation and make the project highly scalable.

### **7.3 Conclusion**

With the growing demand of power and increased cost of its provision, conservation of energy has become a very vital necessity for many households and organizations. The Government is gradually introducing measures to help reduce the cost of electricity, however, the nullifying effect of increased demand makes it very difficult for only measures provided by the government to solve the current predicament of high electricity billings. However, the emergence of novel technologies has presented the country with several opportunities, driving it towards the right direction in solve the problem. This project identified the possibility of using home automation and real-time electricity monitoring technologies to help reduce the cost of electricity for households.

The implementation of the Ma Maison system involved the interaction between several independent components which were built using technologies such as Arduino, Arduino GSM-MQTT library, MQTT.JS library, phpMQTT library Chart.JS library, PHP, HTML, TypeScript, JavaScript, CSS and a few others. The system can provide real-time monitoring of appliances' electricity consumptions. It is also capable of providing remote control functions of connected appliances. Most importantly, it provides historical data in the form of graphs and charts that can help inform a home owner in making decisions to help reduce electricity consumption and thereby, reduce electricity billing.

This project proves the possibility of creating a cost-effective real-time electricity monitoring and remote-control system that has the potential to aid in reduction of electricity consumption.



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```
//incase connection is lost . this automatically reconnects
```

```
if (mqtt.connected()) {
    mqtt.loop();
} else {
    // Reconnect every 10 seconds
    unsigned long t = millis();
    if (t - lastReconnectAttempt > 10000L) {
        lastReconnectAttempt = t;
        if (mqtt.connect()) {
            lastReconnectAttempt = 0;
        }
    }
}

void mqttCallback(char* topic, byte* payload, unsigned int len) {
    mySerial.print("Message arrived [");
    mySerial.print(topic);
    mySerial.print("]: ");
    mySerial.write(payload, len);
    mySerial.println();
}
```

```
// Only proceed if incoming message's topic matches
if (String(topic) == topicled) {
    ledStatus = !ledStatus;
    digitalWrite(LED_PIN, ledStatus);
    mqtt.publish(topicledStatus, ledStatus ? "1" : "0");
}
}

void _switch(char loadId, char key) {
    if (strcmp(key, "on")==0){
        digitalWrite(loadId, LOW);
    } else if (strcmp(key, "off")==0){
        digitalWrite(loadId, HIGH);
    }
}
```

Figure A.1

```
void setup() {
    pinMode(R1, OUTPUT);
    pinMode(R2, OUTPUT);
    pinMode(R3, OUTPUT);
    pinMode(R4, OUTPUT);

    // setting up the pzem
    Serial.begin(9600);
    pzem2.setAddress(ip2);
    pzem3.setAddress(ip3);
    pzem4.setAddress(ip4);

    // initialize the lcd
    lcd.init();
    lcd.backlight();
    lcd.clear();
    lcd.setCursor(0,0);
    lcd.print("Welcome to Ma Maison");

    pinMode(LED_PIN, OUTPUT);

    // Set console baud rate
    mySerial.begin(115200);
    delay(10);

    // Set GSM module baud rate
    SerialAT.begin(115200);
    delay(3000);

    // Restart takes quite some time
    // To skip it, call init() instead of restart()
    lcd.clear();
    lcd.print("Initializing modem...");
    modem.init();

    // Unlock your SIM card with a PIN
    //modem.simunlock("1234");

    lcd.clear();
    lcd.print("Waiting for network...");
    if (!modem.waitForNetwork()) {
        lcd.print("fail");
        while (true);
    }
    lcd.print(" OK");
}
```

Figure A.2

## Appendix A

## Arduino Sketch for Microcontroller

## Appendix B

### PHP Server Side Scripts

```

* @author : Kingsley Yankson
* Mahason
*/

require("phpMQTT.php");
require("database/obscript.php");

$server = "test.mosquitto.org";
$port = 1883;
$username = "";
$password = "";
$client_id = "phpMQTT-publisher"; // make sure this is unique for connecting to server - you could use uniqid()

$GLOBALS['$dbcon'] = new dbscript();

$topic1['King/Mahason/'] = array("qos" => 0, "function" => "onMessage");
$topic2['King/Mahason/Light'] = array("qos" => 0, "function" => "onMessage");
$topic3['King/Mahason/Switch1'] = array("qos" => 0, "function" => "onMessage");
$topic4['King/Mahason/Switch2'] = array("qos" => 0, "function" => "onMessage");
$topic5['King/Mahason/switch'] = array("qos" => 0, "function" => "onMessage");
$topic6['King/Mahason/Light/event'] = array("qos" => 0, "function" => "onMessage");
$topic7['King/Mahason/switch/event'] = array("qos" => 0, "function" => "onMessage");
$topic8['King/Mahason/switch2/event'] = array("qos" => 0, "function" => "onMessage");
$topic9['King/Mahason/TT_consumption'] = array("qos" => 0, "function" => "onMessage");

$mqtt = new phpMQTT($server, $port, $client_id);

if ($mqtt->connect(true, NULL, $username, $password))
{
    $mqtt->subscribe($topic1, 0);
    $mqtt->subscribe($topic2, 0);
    $mqtt->subscribe($topic3, 0);
    $mqtt->subscribe($topic4, 0);
    $mqtt->subscribe($topic5, 0);
    $mqtt->subscribe($topic6, 0);
    $mqtt->subscribe($topic7, 0);
    $mqtt->subscribe($topic8, 0);
    $mqtt->subscribe($topic9, 0);

    $mqtt->publish("King/Mahason/", "Connected and Ready");
}
else
{
    echo "Time out!\n";
}

function record($topic, $message)
{
    $dbcon = $GLOBALS['$dbcon'];
    if ($topic == "King/Mahason/Light")
    {
        $msg = (int) $message;
        $deviceId = $dbcon->getDeviceId("Lamp");
        $dbcon->recordApplianceConsumption($msg, date("Y-m-d"), date("H:i"), $deviceId);
    }
    elseif ($topic == "King/Mahason/Switch1")
    {
        $msg = (int) $message;
        $deviceId = $dbcon->getDeviceId("Switch1");
        $dbcon->recordApplianceConsumption($msg, date("Y-m-d"), date("H:i"), $deviceId);
    }
}

```

Figure B.1

```

* A function to performs the connection to the Mahason database
* @return boolean true if successful
*/

private function getInstance(){
    //create new connection if its doesn't exist already
    if ($this->dbcon == null) {
        $this->dbcon = mysqli_connect('localhost', 'root', 'King', 'Mahason');
    }
    //exit if database connection fails
    if ($this->dbcon->connect_error) {
        die("The connection to the database failed");
    }
    return true; //return connection for use
}

public function getMonthlyData()
{
    $mons = array();
    $vals = array();
    $sum = 0;

    if ($this->dbcon == null) {
        $this->getInstance(); //if connection has not been created, create one
        //perform connection
    }

    for ($x = 1; $x <= 12; $x++)
    {
        $s = "2018-" . $x . "-01";
        $e = "2018-" . $x . "-31";

        $sql = "SELECT * FROM ApplianceConsumption WHERE `date` between '" . $s . "' AND '" . $e . "'";

        $execute = $this->dbcon->query($sql);

        if ($execute == true)
        {
            while ($row = $execute->fetch_assoc()) {
                $vals[] = $row;
                //var_dump($sql);
                $sum = $sum + (int)$row["consumption"];
                //var_dump($sum);
            }

            $mons[] = [$s, $sum];
            $sum = 0;
        }
        else {
            return false;
        }
    }

    return $mons;
}

```

Figure 8B.2

## Appendix C

### Evidence of System Testing

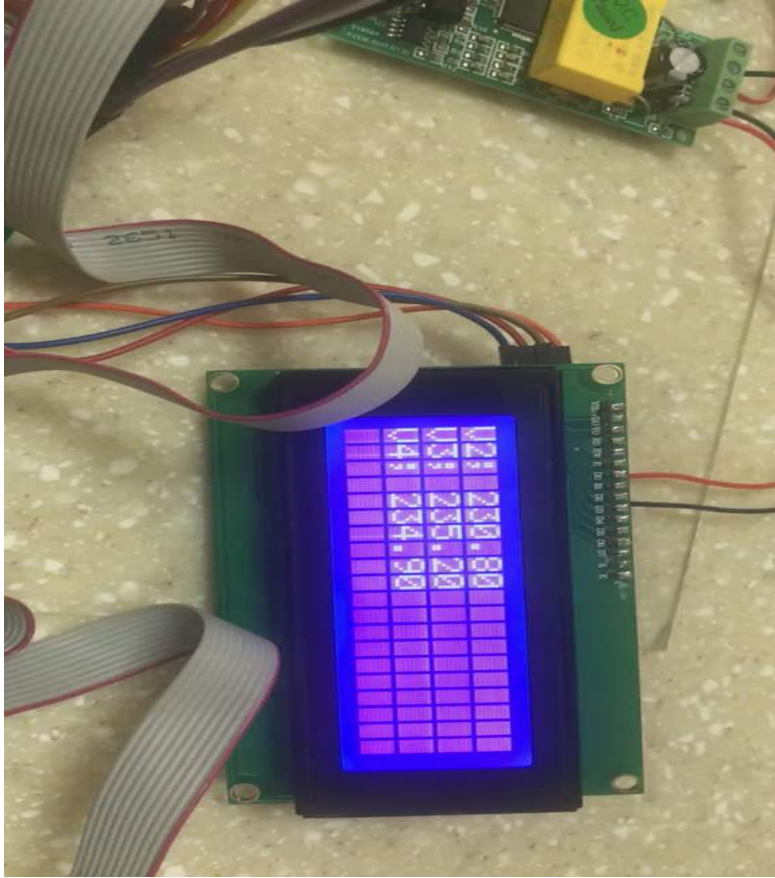


Figure C.1 Testing of local display of voltage readings

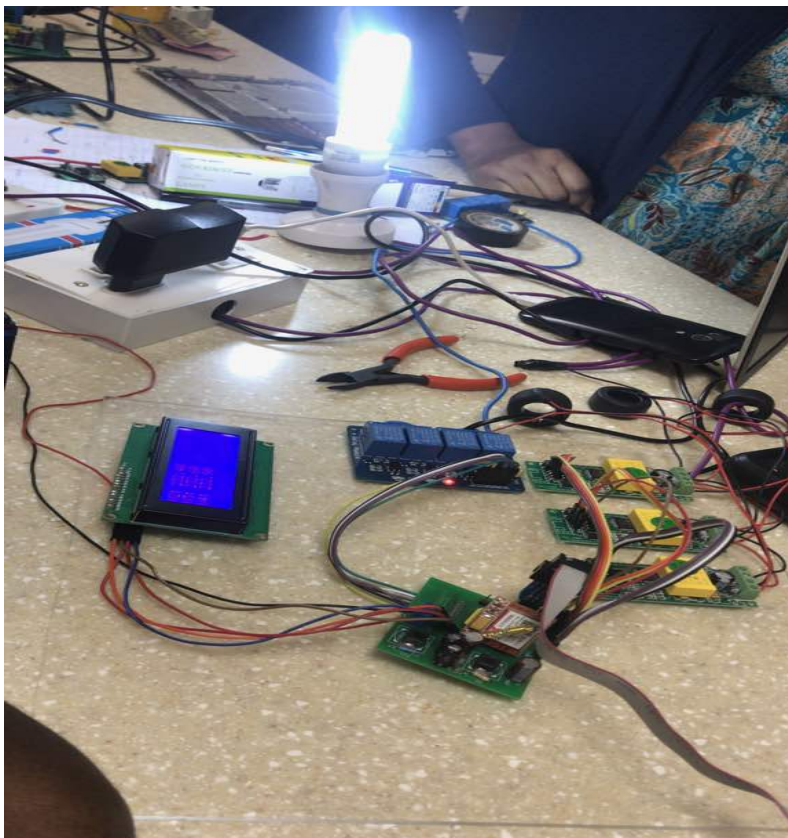


Figure C.2 Testing of appliance control using mobile application