IoT APPLIED TO HOME AUTOMATION

A Degree Thesis Submitted to the faculty of the Escola Tècnica d'Enginyeria de Telecomunicació de Barcelona Universitat Politècnica de Catalunya

by

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Abstract

This project aims to use HTTP to standarize the way IoT devices are managed. By setteling down requirements for every *Smart Object*, it is achievable the coding of an application which, only using HTTP-based interactions, is capable of fully manage a device. For the design of the whole enviroment, there are two roles defned, the *Smart Object*, referred to the distribute devices and the *Core Server* referred to the application which will manage them. Paradigms like RESTfull web services, MVC web applications using Symfony, Energia and Arduino-like coding for the low level devices among others are used in this project.

Resum

Aquest projecte té com a objectiu estandaritzar la manera en que els dispositius es gestionen amb el Internet de les Coses (IoT). Definin uns requeriments clars per a cada dispositiu que es vulgui gestionar, és possible la programació d'una aplicació que, mitjançan l'ús exclusiu del protocol HTTP sigui capaç de gestionar qualsevol dispositiu dsitribuït. Per al desenvolupament de la infraestructura, es defineixen dos rols principals, el de *Smart Object,* el qual es refereix als dispositius de baix nivell distribuïts, i el de *Core Server*, que fa referència a l'aplicació que els gestiona. S'han adoptat paradigmes de disseny tals com serveis webs RESTful, el patró MVC per a aplicacions web (fent servir el framework Symfony), Energia i Arduino per a programar les funcionalitats de baix nivell entre d'altres.

Resumen

El presente proyecto pretende usar HTTP con el objetivo de estandarizar la manera de gestionar dispositivos IoT. Definiendo unos requerimientos claros para estos dispositivos, es possible crear una aplicación que sea capaz de gestionarlos usando únicamente interacciones mediante HTTP. Para el diseño de la infraestructura, se definen dos roles muy claros. El primero responde a *Smart Object*, el cual pretende representar a los dispositivos distribuidos. El segundo responde a *Core Server* y será la aplicación encargada de gestionarlos. En este proyecto se usan patrones o paradigmas de diseño de software como los servicios RESTful, aplicaciones web siguiendo el patrón MVC (mediante uso del framework Symfony) asi como Energia (Arduino) para la programación de bajo nivel.

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1. Introduction

1.1 Application Transport Protocol

1.1.1 Internet Protocol

We all know this protocol nowadays, the protocol that aimed a global network, with all its components uniquely identified and all reachable between them. It is not a matter whether it is connectionless or not or other specifications, but its addressing method was good enough to turn the world into a single network.

The inmediately above layer, the transport one, is standarized as well being Transmission Control Protocol (TCP) the most used for that layer. As the technology available never was as fast as it is nowadays, other protocols aiming faster communications yet less secure communications appeared, such as the well known User Datagram Protocol (UDP).

Once that layer is reached, it is all about the *Application layer*. At this point, the amount of protocols available is huge, so vaste that it is absolutely impossible to find one as standarized as Internet Protocol.

In my opinion, that is a matter of the past. The technologies and infraestructures we have nowadays, permit to process internet traffic at a very high speed, that having to treat an internet packet up to application layer would be comparable as what that meant for layer 3 for example, 20 years ago. What that really means, is that a low-consumption processor, a simple one, is nowadays capable of processing a package up to application layer in a really fast way.

There are a lot of prototyping boards whose come with an embbeded processor dedicated only to the internet protocols stack. That is, with libraries available to make it easy for a junior developer to have its termometer connected to the internet in a fast and easy way.

1.1.2 Application Protocol

Just having a look at how is software developing in general terms evolving, I think that the trend of the coding is to use the application layer as a transport layer. That would mean that the global network which IP pretended to reach, would easily become a global application. In terms of coding efficiency, that would dramatically decrease the effort needed to code an application and to distribute it among the global network.

Imagine you would want to code a simple application using your own Application layer implementation. If you would use JAVA, actually the preferred coding language by ETSETB professors to code applications, you'd need to use all JAVA libraries which implement IP addresing protocols and sockets to implement transport communications. That means the starting point and the coding scenario would be application layer.

The major problem with that coding strategy, is that your application is not standar

at all. The data you manage, your persistence system, your identifiers for your objects, the whole application would be *privative,* making it impossible for other developers to easily add funcionalities to it. There is obviously the option to publish an API, just like Oracle does with Java, to let people now how you work. But anyway, it is how *you* work and others should *learn* your work to use your API.

1.1.3 HTTP, Application Transport Protocol

HTTP is a simple connectionless protocol, with a few methods and simple headers (a deeper study would be done on HTTP later on). It was mainly designed to identify and route static resources (through Universal Resources Identifiers, URI's). The use of this protocol is a bit more complex nowadays, it is used to fit almost any need. It even is capable of managing streaming through an specific protocol named Dynami Adaptative Streaming over HTTP.

With that, it looks like a great protocol to reach that *Application Transport Protocol*, as long as it is possible to embbed a lot of parameters (enviroment variables) through its requests and also can transport any kind of data yet the recipient of that data must be prepared to manage it (and that is where the term *transport* fits perfectly for me).

1.1.4 HTTP and a Global Application idea

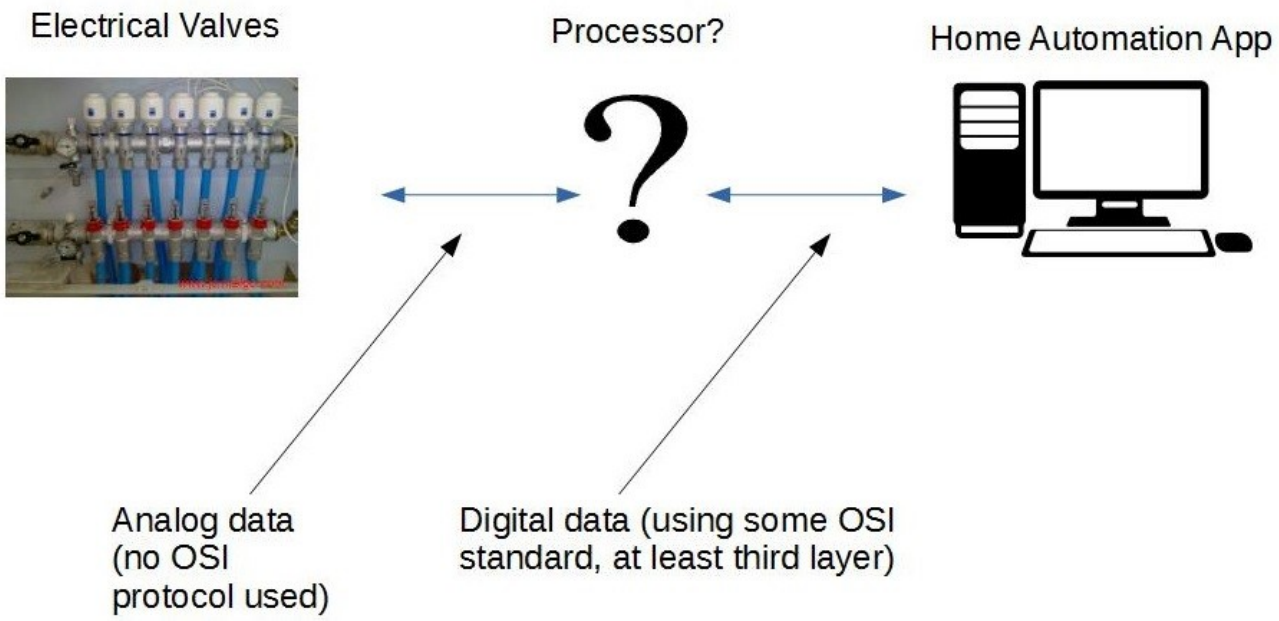
So if we would manage it to implement all the Machine to Machine communications over HTTP, we would be rising the whole communications process up to the Application Layer. As long as that layer was concieved to be complex and prepared to manage high-level applications, it would be achievable to have a global distributed application. No matter the coding language which was used to code specific applications, if them all would use HTTP to manage its resources (either local or distributed), to add funcionalities to such an application even in another programming language would be achievable.

1.2 Project's Background&Goal

1.2.1 Background

The idea of this project came out by the hand of an uncle of mine. He is a Computer Science engineer and has got a business idea in the Home Automation field. His whole intention and thoughts on his project does not matter at this point. He knows about my Telecomuncation Science degree, and one day he came to me with a simple question. He had got one need, and I was supposed to try to work some solution out.

The next drawing represents the most basic idea which needed a solution:



Drawing i: Basic idea

1.2.2 Project's Goals

The goal of that project is to come out with a solution for the need my uncle's noticed. A low-cost processor in between analog devices and the end application to make all the M2M communications as standarized as possible thus achieving the abstraction of distributed devices (thus being able to use all Object Oriented Programming strength).

1.3 Requirements and specifications

The following are the initial Requirements defined at the begining of the project.

Board requirements:

- Implementation of the full OSI protocol stack (wifi for the physical layer)
- Act as the interface where analog devices would be plugged in
- Low cost - Low power consumption
- Board self-registration to the server

Server requirements:

- Easy-to-use user interface
- Analyze and operate data
- Reliable persistence system

- Should hide M2M performance

Those above have not changed despite they are not very specific. What have changed due to developement ot the project are the specifications.

Elements to comply with the specifications:

Project specifications:
Board:

- OSI Stack (provided by TI CC3200)
- Energia (C/C++)

HTTP web server:

- RESTful service
  - Define URL pattern
- Define start-up protocol between board and server
  - Self registration of the board into the server
    - POST all the information necessary into the server
- Functionalities reachable through GET method and query string only
- No pattern applies to this software (no OOP)

Server

- Symfony-based
- Startup Bundle: ready to manage the startup info sent by the board and flush it to its persistence system
- Device Bundle: bundle ready to manage each device

2. State of the art of the technology used in this thesis:

2.1. Internet of Things

"The connection of *physical things* to the Internet makes it possible to access remote sensor data and to control the physical world from a distance. The mash-up of captured data with data retrieved from other sources, e.g., with data that is contained in the Web, gives rise to new synergistic services that go beyond the services that can be provided by an isolated embedded system. The *Internet of Things* is based on this vision. A *smart object*, which is the building block of the Internet of Things, is just another name for an embedded system that is connected to the Internet. There is another technology that points in the same direction – the *RFID technology*. The RFID technology, an extension of the ubiquitous optical bar codes that are found on many every-day products, requires the attachment of a smart low-cost electronic ID-tag to a product such that the identity of a product can be decoded from a distance. By putting more intelligence into the ID tag, the *tagged thing* becomes a *smart object.* The novelty of the Internet-of-Things (IoT) is not in any new disruptive technology, but in the pervasive deployment of *smart objects*." - Quoted from *Real Time System* written by *Hermann Kopetz.*

The aim of this document is to study a possible implementation of what Hermann Kopetz points out in his definition of *IoT*. That is, to make the low-level devices distributed in a home automation system smart enough to send it's data to a core machine placed elsewhere in the internet in a high-level format. Particularly, HTTP based messages. From now on, this distributed and smart device will be called *Smart Object* (to follow Hermann's term) and the more intelligent core machine will be called *Core Server.* From the view of Object Oriented Programming (OOP) and following Hermann's definition, this plus of intelligence given to the low-level devices transforms the idea of device into the idea of an object (referred to OOP coding environment). That means that the coding of an application where such *Smart Objects* are used comes to meet all the OOP paradigms, as we will talk about objects from now on, such abstraction, encapsulation, inheritance and polymorphism.

2.2. RESTful services

Web services are becoming really popular because they are fully oriented to network-based applications. They are commonly used to hold http servers with a wide range of functionalities. Nowadays, there are two schemes of web service whom rule the scene. The first one I want to mention, is SOAP. SOAP based web

services are ruled by a server-client architecture. The client of a SOAP service needs to know how the server works before it is able to use it. This is done via an XML called Web Services Description Language (WSDL), where all the actions and methods the server can perform are described, making it possible to the client to connect to the service and gather its resources. SOAP was not chosen for this project due to its implementation complexity.

The second web service schema and the one that fits the simplicity needed for this project is Representational State Transfer (REST) service. Its architecture was designed and first drew by Roy Thomas Fielding in his Doctoral thesis *Architectural Styles and the Design of Network-based Software Architectures.* Out from Roy words, and this is my own interpretation, REST services are ideal to emulate a data base. So, it is like a database built on top of HTTP (application layer) and that is why its use is growing exponentially.

A REST service which follows Roy's *rules* (which are actually assumed as a standard) may store *resources*, or as he says, *Data Element*.

As in any application which stores data this way, CRUD (Create, Read, Update, Delete) methods are needed. In the case of REST services, to keep them as simple as possible, those actions can be performed with the native HTTP methods (POST, GET, PUT, DELETE) respectively.

Now, to understand the way REST is used in this document, lets have a look at how Roy defines a *Data Element* and its attributes.

The following table was extracted from his thesis.

Data Element	Modern Web Examples
resource	the intended conceptual target of a hypertext reference
resource identifier	URL, URN
representation	HTML document, JPEG image
representation metadata	media type, last-modified time
resource metadata	source link, alternates, vary
control data	if-modified-since, cache-control

Drawing ii: Data element definition

As we can see, each *Data Element* stored by a REST service provider must be pointed by an identifier, and as we can also see, this identifier is an URL. I give now a little example on how to use this identifiers.

Imagine we want to store people in a REST service, and we idenitfy each person by an URL, for example:

Roy → http://service:80/people/roy

Once we perform a GET (read) method over this URL, we will get a response from the server and that would finish the interaction. In the response we will get, apart from the data itself, which format has been used to code the data (most common are JSON and XML). So we only need a parser prepared to decode this format to get the data back.

In the Roy's REST architecture, as we only need to perform CRUD actions, the URLs used in such a service might not contain any verb. I mean, the action is performed via the HTTP method, and the URL is just the identifier which the action will be performed to.

This project is REST based but doesn't follow Roy's standard. The reason why we depart from the standard can be explained with a simple example (which is just a touch of what is going to be explained in latter parts of the document).

Imagine now we have got a relay turned into a *Smart Object* capable of connecting to the internet and holding a web server. Next, we define that a relay has got only three functionalities, to be activated, to be deactivated or to be requested for its state. If we want to perform all the M2M communications between the *Core Server* and this relay via HTTP, it looks like a good solution to achieve this to make this relay to hold a REST service.

Lets see what would happen if we would not follow Roy's rules as they are exactly defined:

HTTP method	Resource	Identifier	Purpose
GET	relay	http://relay:port/id/info	Retrieves information about the relay's state
GET	activate relay	http://relay:port/id/activate	Activates the relay
GET	deactivate relay	http://relay:port/id/deactivate	Deactivates the relay

Drawing iii: REST bad practice

At a first glance we can see this is not actually correct. The only action that would be under Roy's approval would be the first one, because the action (read) is performed directly from the http method GET and the response contains a simple information (does not matter its format at this point).

The others are not correct, because they are not pointing to a *Data Resource* explicitly, they point actions which the device holding the service can perform. It does not even fit the *Data Resource* definition, so, this may not be considered as a bad practice (in terms of Roy's rules) in this particular case.

There is actually a way to perform the same actions following Roy's rules, but adds complexity to the distributed device (the relay in this example) and also makes the URLs a little bit more complicated. The following table shows how to perform the described actions using HTTP's query string.

HTTP method	Resource	Identifier	Purpose
GET	relay	http://relay:port/id	Retrieves information about the relay's state
GET	activate relay	http://relay:port/id?action=activate	Activates the relay
GET	deactivate relay	http://relay:port/id?action=deactivate	Deactivates the relay

Drawing iv: REST good practice

With this method we would not break any rule as the action (READ) maintains the same for the three URLs, but the latter two have got a parameters passed via the query string, and that is totally allowed in Roy's *pseudo-standard*.

To conclude, the project will not be developed following those rules as the *Smart Objects* does not actually fit the *Resource Data* definition. The project will be developed as explained in the first part of the former example.

2.3. PHP

PHP is a wide-spread scripting language. It is an interpreted language and became real popular in server-side applications due to its simplicity to code and its availability to be mixed up with HTML code, reason why it became popular among web applications developers.

This language has grown without the hold of a company, it all comes out from a community which has written libraries for almost any application you can think of. That is one reason I have chosen it, it is a great pennant of what Free and Open Source Software (FOSS) means. Despite that, nowadays, it is not only a scripting language, as it can be used in OOP coding. In my opinion, its rival has always been Java, but there are lots of programming languages which can perform the requirements of almost any application (Ruby, Python, C++, C#, etc).

2.4. Symfony

Symfony is the real reason why PHP was chosen for this project. It is a framework developed by a French company called Sensio Labs. It is open source and implements the Model-View-Controller programming pattern for its applications.

It actually implements a slightly customized version of the Model-View-Controller pattern.

First, a little review on what MVC coding pattern aims.

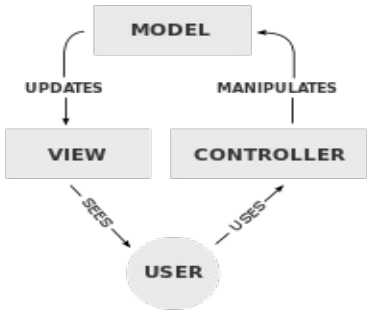
The main aim of a pattern is to let developers write and code applications which would be *easily* modified in the future. That is to follow a kind of *skeleton*, in fact, a *pattern* so it might be easy to track and separate the functionalities of the application.

2.4.1 MVC Pattern Components

Model – Represents the information, the data that the application manages.

View – It can request and retrieve information from the model and generates a view for the user.

Controllers – It runs the logic of the application. Based on the actions performed by the user, they manipulate de data of the model and render the view what should be displayed.

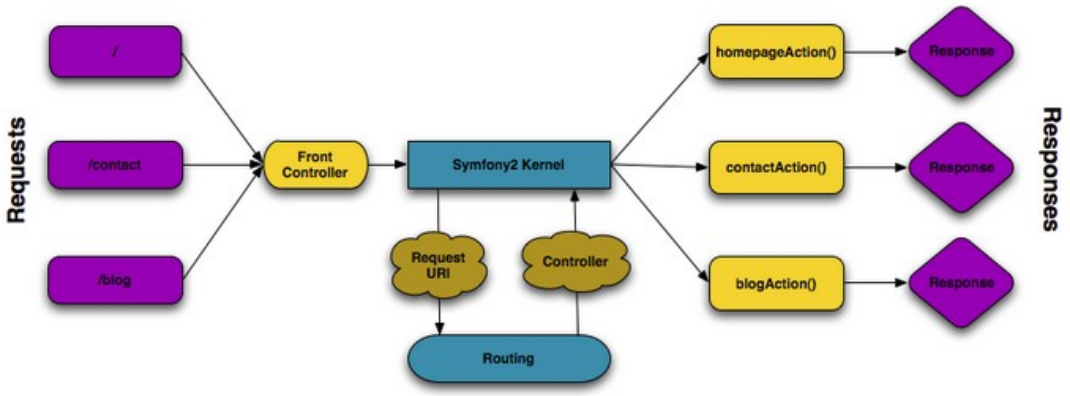


Drawing v: MVC Flow

2.4.2 Symfony fundamentals

Now a brief on the huge amount of documentation available on its home page (https://symfony.com/), just to understand its fundamentals and why it has been chosen for this project.

Symfony, as long as it is a framework, takes MVC and implements it in a poor abstract way. The following picture taken from the *Symfony book*, shows its basic flow.



Drawing vi: Symfony basic flow

As can be seen, all the HTTP requests to a Symfony application first go through what they call a *Front controller.* It basically parses the url requested and checks it out to its *Routing* table, but ¿What is a *Routing table?*.

In Symfony, every URL matches a *Controller*. So the Front controller, checks the route out and finds its related controller. The controller then, has got a method prepared to handle that specific URL. It might perform changes to the database (model in MVC), or any logic it has been coded to and finally retrieves a View to the user. This part can not be explicitly seen in the above picture, but the *Response* we can see at the end of the drawing, always renders a view.

To get an idea on how this flow looks in code, a little of example of a request (https://symfony.com/doc/2.7/book/http_fundamentals.html).

First, a look to the *Routing table:*

```
<!-- app/config/routing.xml →

<?xml version="1.0" encoding="UTF-8" ?>

<routes xmlns="http://symfony.com/schema/routing"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://symfony.com/schema/routing
        http://symfony.com/schema/routing/routing-1.0.xsd">
    <route id="contact" path="/contact">
        <default key="_controller">AppBundle:Main:contact</default>
    </route>
</routes>
```

In the code above we can see a single route defined which matches the relative URL */contact*. Also, as defined between the *route* tags, it is defined that every time this relative path is matched, the controller which must be activated to handle this particular request is the one under the name *AppBundle:Main:contact.*

This controller may look as simple as follows:

```
// src/AppBundle/Controller/MainController.php
```

```
namespace AppBundle\Controller;

use Symfony\Component\HttpFoundation\Response;
class MainController
{
    public function contactAction()
    {
        return new Response(Path:to:a:view);
    }
}
```

The response, as I pointed out before, retrieves a view (which can be a simple HTML page).

2.4.2.1 Bundles

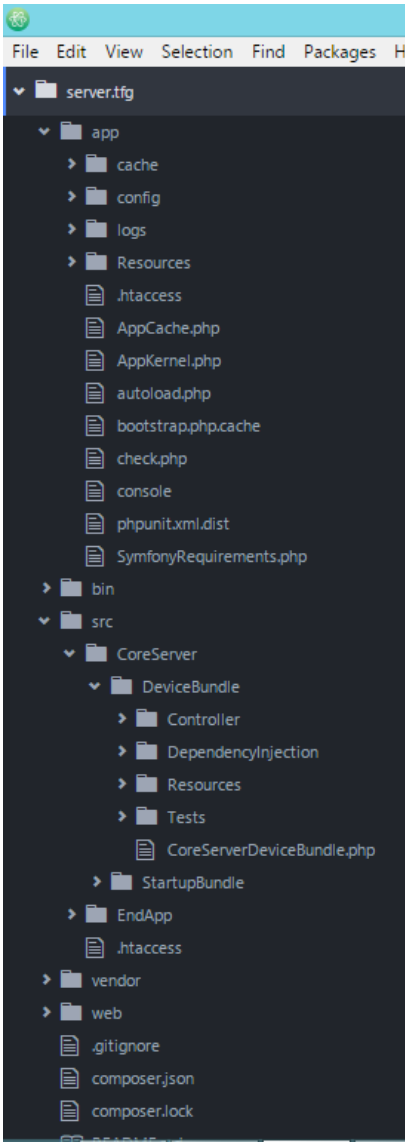
The last term I think is important to understand why Symfony has been chosen, is the Bundle concept.

The working flow of Symfony belong to its core. A Symfony developer may dive into the implementation of its front controller its libraries and all the stuff that makes all the framework's flow explained before possible, but it is not a need to use this tool.

So, ¿When does a developer take action in a Symfony application? The answer is indeed, writing bundles.

A bundle is a set of resources fed from Symfony libraries which contains specific Controllers, Routes and Views. It could be seen as a little application inside Symfony, There is a huge amount of third-party bundles which people develop to reach specific needs.

Basically, a Symfony application always have the same structure.



Drwaing vii: Symfony project tree

/app

Symfony's core, it contains all the configuration files, bundle's imports, etc.

/src

Here is where the developer codes his bundles.

/src/Project/UserBundle

There we can see how a bundle is organized, with its Controllers, its Routes and its Views.

/vendor

All the libraries Symfony uses and the third-party bundles you might have installed.

/web

Here Symfony stores the Front Controllers and performs its own mechanism to keep control of all the css, js, images, static files and resources of this kind that the application may use.

So a bundle is a separated portion of code implementation with its own routes and controllers. Once you have got your bundle written down, you just have to tell Symfony that it must be included in the whole application flow. In the main Routing table (/app directory) you must import your Bundle's routes. Finally, you must add your bundle to the AppKernel php class (/app directory) and the bundle will become fully operational.

This provides a huge load of felxibility to the application because it is pretty easy to add or remove bundles. In the following chapter we will show how to take advantage of this tool in this project.

2.4.2.2 Doctrine

Doctrine is the database engine which links the persistence system (database) with the Symfony application. It is written in PHP and can be used absolutely dettached of Symfony, but as long as it is developed by the same company, it comes with Symfony by default. I do mention it because it is going to be the engine to interact with the *Core Server* database.

2.4.2.2.1 DAO Pattern

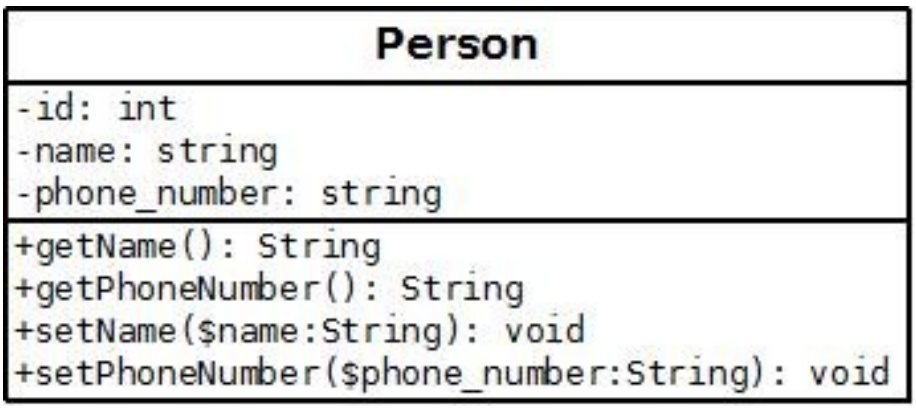
Doctrine uses the Data Access Object pattern to make it able to the application to treat database tables as if they were regular OOP classes. Those interface classes which map the database resources with the object the application will eventually use are called *Entities*.

For example, if we would have a database table such as the following one:

People		
ID	Name	Phone number

Drawing viii: DAO table

Doctrine would only let us acces to its rows using its classes if we would tell it that, to map those resources, the *Entity* it has to use is the following PHP class:



Drawing ix: DAO class example

As it can be seen, basically a DAO class has got attributes and methods (called *getters&setters*) to externally (from other classes) access and modify its attributes.

Thus, each time we would perform a query using Doctrine's libraries, it would map the SQL data (in case the database is powered in SQL) to that PHP class and Doctrine would instantiate an Object for each row.

This is why it is mandatory to implement *getters&setters* in order to make its parameters reachable by Symfony's PHP classes. As simple as that.

3. Project developement

Through this chapter, I am going to explain the developement and implementation of what I considered the two main roles in the proposed infrastructure. The first one is *Smart Object,* which is the distributed device. Here I will define which requirements should accomplish those devices to work properly with my definition of *Core Server.* When I'll come to explain my proposal of implementation, I would like to settle that it is just that, a particular implementation, meaning that any device fulfilling those requirements would work properly no matter the language it is written with. Thus, adding flexibility to the whole enviroment (or infrastructure).

The second role is the *Core Server,* which will manage those devices from the server-side. In this case it is not possible to be as flexible as in the *Smart Object* role, as long as only the bundles written in PHP using Symfony will be able to work with this *Core Server*. The flexibility remains the main goal, providing that Symfony is concieved to be flexible itself.

The last part of the chapter shows a simple implementation of what might be considered as an example of end-user application. It is a simple web page (coded using Symfony) which lists all the devices and permits the proper actions with them.

3.1 Smart Object

This term comes from the *Internet of Things* verbose. What this project is seeking, is to try to abstract a particular device implementation and to be able to use it as a regular OOP object, making it possible to communicate with it through a high-level protocol, in this case, HTTP.

In order to make this system capable of managing any low-level device we found it necessary to define a model for the smart objects suitable for any device.

3.1.1 Data model

After looking for the specifications of several devices, and here the vaste experience of my professor was unestimable, we concluded that, no matter what the device is, it always can be classified following the next properties:

A device can be..

ACTIVATABLE

Those which can be forced to change their state. The activate action is performed by the *Core Server*.

LAUNCHER

Those which are able to launch events when their state changes. The state change does not come from the *Core Server.* Thus, it may be an opened window, an opened door, a light sensor, etc.

READABLE

Those who respond some data when are asked for it.

A part from that, a device can manage the following data models:

BINARY

The device is only capable of managing two values.

FINITE

The device is capable of managing a finite range of values (from 0..n-1).

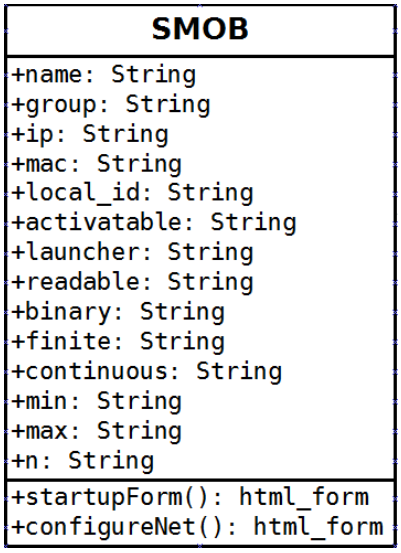
CONTINUOUS

The device can manage any value between a Max and a Min.

Thus, any time we would like to add a particular device to this system, it would be mandatory to do the job of classifying it in this patterns. With that, it is possible to settle the specifications of a *Smart Object*.

3.1.1 Smart Object Requirements

From the point of view of OOP, an Smart Object looks as follows:



Drawing x: SMOB class

All of the parameters are *typed* as *String* just because the data in the M2M communications *Smart Object – Core Server* will be sent through HTTP query string.

3.1.1.1 Startup requirements

Every *Smart Object,* when it has got internet connection, must connect to the *Core Server* it has defined to work with and send some parameters. Those paramteres should be encoded as a POST request and sended to the *Core Server* via a HTML form.

To get a bit deeper on how a *Smart Object* works, we have to take into account that a device does not become smart magically. It must exist a processor between

the device and the *Core Server*. This processor must be capable of connecting to the internet. For that reason, and to try to embrace any configuration, there si an important parameter that must be taken into account, which is, local_id. The next table shows those name-value pairs for a single *processor/board* holding 4 devices:

Name	Value	Description
macaddress	00:00:00:00:00:00	MAC Address. Used by the application as a board ID
ipaddress	192.168.0.123	The current IP address of the device
name0	relay0	The name w e consider adequate for that device
group0	relays	The group w e consider this device should belong to
local_id0	0	A board-local identifier
activatable0	true	This device is activatable
binary0	true	This device's data is binary
name1	blind0	The name w e consider adequate for that device
group1	blinds	The group w e consider this device should belong to
local_id1	1	A board-local identifier
activatable1	true	This device is activatable
continuous1	true	This device's data is binary
max1	89	The maximum value of this device's range
min1	23	The minimum value of this device's range
name2	temp0	The name w e consider adequate for that device
group2	temps	The group w e consider this device should belong to
local_id2	2	A board-local identifier
readable2	true	This device is readable
continuous2	true	This device's data is binary
max2	110	The maximum value of this device's range
min2	-110	The minimum value of this device's range
name3	reed0	The name w e consider adequate for that device
group3	reeds	The group w e consider this device should belong to
local_id3	3	A board-local identifier
launcher3	true	This device is activatable
binary3	true	This device's data is binary

Drawing xi: SMOB startup requirements

When preparing a board to hold devices, it is a must to say in the startup form the name, the group, the local_id, what properties and what values does the device implement (only the implemented properties should be sent, the *Core Server* will understand that the ones whose were not sent, are not implemented).

With these parameters, the *Core Server* will be able to have a unique access route to every device working in its system.

Every time a *Smart Object* restarts, depending on the implementation, it might be possible that sends this startup info to the *Core server* again. The *Core Server* then, must be intelligent enough to discard devices it already have controlled.

3.1.1.2 Production requirements

Once the *Smart Object* is running and it is been identified by the *Core Server*, it is time to work in a production enviroment. That means that every *Smart Object*

must be capable of running a HTTP server, but to act as a HTTP client too.

3.1.1.2.1 Smart Object URL pattern action

The particular funcionalities of any *Smart Object* must be reachable following the next URL pattern:

```
http://smart_object_ip:port/local_id/action
```

3.1.1.2.2 Smart Object URL pattern with parameters

If for any reason, the action to be performed by the object has got any parameters, those must be attached in the request using the query string. Thus, an action with two parameters should look like this:

```
http://smart_object_ip:port/local_id/action?
        param1=value1&param2=value2
```

3.1.1.2.2 Smat Object URL for network cofinguration

Apart from its functionalities,four network parameters need to be set for an object; ip address, gateway ip, dns server and network mask and also the transport port used to hold the HTTP server.

These information, will be sent by the *Core String* attached to the GET request using the query string. Here is an example of what an URL to configure the network parameters of a given *Smart Object* should look:

```
http://smart_object_ip:port/netConf?ip=xxx.xxx.xxx.xxx&gateway=
   xxx.xxx.xxx.xxx&dnsxx.xxx.xxx.xxx&maskxx.xxx.xxx&port=xxxx
```

3.1.2 Proposal of Implementation

Once the requirements for those *Smart Objects* are settled down, I explain a proposal of implementation.

For this part I had several options in mind. What I would have loved, is to be able to write the code for an object in a high level programming language such as PHP or Java, due to its amount of libraries and easy to understand code. Unfortunately, the processors embedded in the boards used for IoT, are Cortex M4 based, which is actually comprehensible due to its low resources consumption and fast and simple performance. Thus, no high-level programming language was available.

The second alternative I thought of was raw C. I discarded that quickly because, as we know, C is an structured language. Thus it is not flexible enough for me, as long as this is a proposal of implementation, I would not spend the time required to develop a HTTP server capable of parse and send request with query string parameters.

My choice was finally Energia. Energia is an Arduino-based integrated development enviroment (IDE) created by Texas Instruments. In the tests for this project a CC3200 demonstration board was used, so it seems obvious to use Energia. Also, Arduino works with two pieces of code, the setup and the loop, fact that suits the *Smart Object* requirements ideally. Now I explain how.

3.1.2.3 Implementation using Energia

3.1.2.3.1 Setup

If we have a look at the startup requirements, it easy to think about this part of Arduino coding to fulfill the specifications.

In this part of the code, the board must get an internet connection (via DHCP or defining the network parameters stragiht in the code) and send the information required to the *Core Server*. In general and abstract terms this setup code would look as shown in the ANNEX I.

3.1.2.3.2 Loop

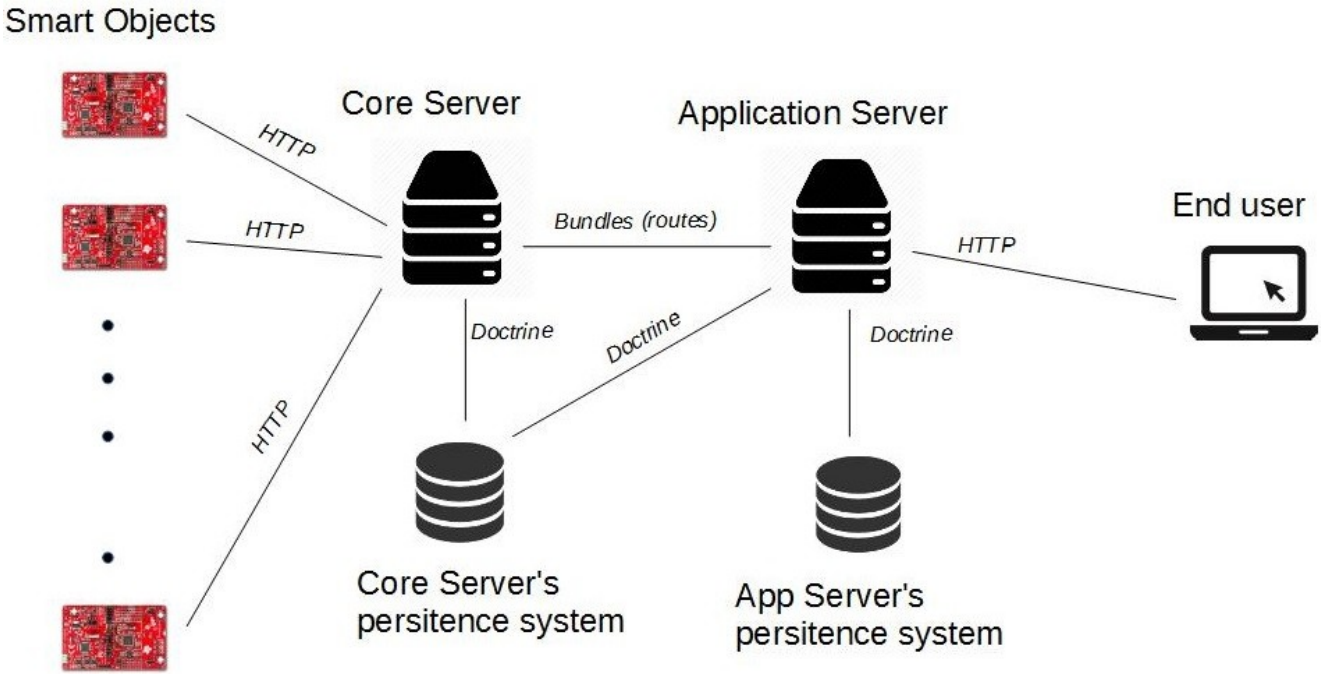
This part of the code will perform the production requirements explained before. The code can be found in the ANNEX I as well.

3.2 Core Server

We have seen the first role of the two main roles that the whole application enviroment has got. I would like to settle, and to clearify, that what I define as *Core Server* is NOT the application itself, but is a kind of interface that makes available to the final home automation application developer the access and control of the resources (in this case, the *Smart Objects).* As the chosen developing enviroment is Symfony, that means that the final application would need to install all the Bundles that pool the *Core Server.*

3.2.1 Working flow

To understand what it's been said before, the next picture shows a diagram where the role of the *Core Server* is shown:



Drawing xii: System working flow

3.2.2 Core Server Requirements and Specifications

As can be seen in the picture above, the *Core Server* will eventually act as a layer between the end application and the *Smart Objects*. Following the path that the design of the *Smart Object*'s requirements left behind, here is also possible to separate the server's functionality in two different tasks. The frist one is to recognize an *Smart Object* and to add it to it's persistence system and the second one, to manage all the possible device's actions.

Out from those ideas, lets define a *Startup Bundle* to fulfill the first requirement, and a *Device Bundle*, to fullfill the proudction requirements.

3.2.2.1 Startup Bundle

Lets notice that the Application using this enviroment, will not know nor have any reference to this StartupBundle (apart from installing and enabling it, of course). This will not be the same in the case of the DeviceBundle, which will have to enable references in order to make it available for the Application the access and management of each device.

Now talking about the StartupBundle. As it has got only one functionalitiy (to recognize and add new devices to its persistence system, if necessary), it will only need one route (the one the *Smart Objects* requests for at startup), one Controller (which will implement the logic of adding it or not) and no view at all, as no user needs to see anything out from this process.

So if we have a look to the startup data which is supposed to be sent by any *Smart Object* when it has got internet connection and acces to the *Core Server*, it will become an easy task to define and write this bundle. Lets see a simple example with a *Board* managing a single device.

Name	Value	Description
macaddress	00:00:00:00:00:00	MAC Address. Used by the application as a board ID
ipaddress	192.168.0.123	The current IP address of the device
name0	relay0	The name w e consider adequate for that device
group0	relays	The group w e consider this device should belong to
local_id0	0	A board-local identifier
activatable0	true	This device is activatable
binary0	true	This device's data is binary

Drawing xiii: startup data

Out from this table, it is possible to settle which tables this bundle will need as to persist the data.

A first table gathering all of the *SmartObjects* and their general information.

DEVICES_ALL											
ID	NAME	GROUP	IP	MAC	LOCAL_ID	ACTIVATABLE	LAUNCHER	READABLE	BINARY	FINITE	CONTINUOUS
int	string	string	string	string	int	boolean	boolean	boolean	boolean	boolean	boolean

Drawing xiv: DEVICES_ALL table

As long as it is not enough with that, it is required two more tables, one defining the values of a *finite* device and the other defining the values of a *continuous* device.

The range of values goes from 0 to N-1 in steps of 1.

DEVICE_FINITE						
ID	NAME	GROUP	IP	MAC	LOCAL_ID	N
int	string	string	string	string	int	int

Drawing xv: DEVICES_FINITE table

Can treat any value from Min to Max.

DEVICES_CONTINUOUS							
ID	NAME	GROUP	IP	MAC	LOCAL_ID	MIN	MAX
int	string	string	string	string	int	int	int

Drawing xvi: DEVICES_CONTINUOUS

With this information the *Core Server* will be able to perform any of its defined actions over any of its persisted objects.

The following two points get down to the developement of this bundle following Symfony's rules.

3.2.2.1.1 Startup Bundle Routes

As my favourite procedure when defining routes in Symfony is annotation straight into the Controller, it will be possible to see both the route and the Controller logic in the next point.

3.2.2.1.2 Startup Bundle Controller

The controller has got only one action, which consists in checking the recieved form out, querying for its object and if not found, add it to the persistence system.

ANNEX I StartupController

3.2.2.2 Device Bundle

This bundle aims to be able to manage any device. That is why the above generic properties have been designed.

In order to access to the database, it has been defined one entity for each database's table. Those can be seen in the ANNEX I – Entities.

3.2.2.2.1 Device Controller

The same way the StartupBundle was explained, both the routes and the actions are defined in the controller. The exact code can be found in ANNEX I – DeviceBundle.

Here I will explain each action, which parameters requires and how it is supposed to perform those actions.

3.2.2.2.1.1 Activatable Action

Route: http://core.server/activatable/binary{board_id}/{local_id}

Function: void activatableBinaryAction($board_id, $local_id)

Performance: send a GET request to http://{board_ip}/{$local_id}/activate

3.2.2.2.1.2 Activatable Finite Action

Route: http://core.server/activatable/finite/{board_id}/{local_id}?value="something"

Function: void activatableFiniteAction($board_id, $local_id, Request $request)

Performance: send a GET request to http://{board_ip}/{$local_id}/activate?param1="something"

3.2.2.2.1.3 Activatable Continuous Action

Route: http://core.server/activatable/continuous/{board_id}/{local_id}?value="something"

Function: void activatableContinuousAction($board_id, $local_id, Request $request)

Performance: send a GET request to http://{board_ip}/{$local_id}/activate?param1="something"

3.2.2.2.1.4 Read Action

For this property, as there is always a returned value, it does not actually matter whether it is binary, continuous or finite.

Route: http://core.server/read/{board_id}/{local_id}

Function: void readAction($board_id, $local_id, Request $request)

Performance: send a GET request to http://{board_ip}/{$local_id}/read

3.2.2.2.1.5 Check Net Action

This aims to gather the network configuration from an Smart Object.

Route: http://core.server/network/check/{board_id}/{local_id}

Function: netCheckAction($board_id, $local_id, Request $request)

Performance: send a GET request to http://{board_ip}/{$local_id}/checkNetConf

3.2.2.2.1.6 Update Net Action

Route: http://core.server/network/update/{board_id}/{local_id}

Function: void netUpdateAction($board_id, $local_id, Request $request)

Performance: send a GET request to http://{board_ip}/{$local_id}/checkNetConf

3.2.3 Implementation

To explain my implementation of the *Core Server* I assume the host machine used holds a LAMP (Linux, Apache, MySQL, PHP) server, that means:

1) The system is Linux-based. In this chapter Fedora 22 is used.

2) The system is running a web server. In this chapter php built-in web server is used.

3) The system has got a MariaDB/MySQL server running.

4) The system has got php installed.

All the pieces of code and references can be found in the ANNEX II. This one is a file-tree for the whole Symfony project.

3.2.3.1 Install Symfony

SensioLabs recently released a Symfony installer. That means, that with php running in your server and having *curl* installed, installing Symfony becomes as easy as explained here http://symfony.com/doc/current/book/installation.html.

These are the two commands necessary:

```
$ sudo curl -LsS http://symfony.com/installer -o /usr/local/bin/symfony
```

As it can be seen, it already enables a command *symfony* in your user bin folder, with that, move to the desired directory to hold the application and execute:

```
$ symfony new my_project_name
```

I created *server.tfg* in my SkyDrive TFG directory:

```
$ cd /media/windows/Users/lucas/SkyDrive/TFG/

$ symfony new server.tfg
```

3.2.3.2 Generate Bundles

Symfony comes with php-written commands to manage a project. I create the following bundles:

1) CoreServerDeviceBundle: already explained its functionality.

2) CoreServerStartupBundle: already explained its functionality.

3) CoreServerEntityBundle: auxiliary bundle to hold the 3 entities that would map to the databse.

4) EndAppHomeBundle: a simulacre on what could be an end application. Just fot test purposes.

Those can be created with the symfony command:

```
$ php app/console generate:bundle
```

3.2.3.3 Routing Imports

In order to be able to apply all the routes defined in the specifications chapter, there must be some changes done on each bundles routing file.

For each bundle the file is located at:

1) /server.tfg/src/CoreServer/DeviceBundle/Resources/config/routing.yml

2) /server.tfg/src/CoreServer/StartupBundle/Resources/config/routing.yml

4) /server.tfg/src/CoreServer/DeviceBundle/Resources/config/routing.yml

3.2.3.4 Configure database

As it is been explained above, I am going to use Doctrine as the DAO layer for the database. Its configuration is pretty easy.

1) Fullfill the data required in /server.tfg/app/config/parameters.yml

```yaml
# /server.tfg/app/config/parameters.yml
parameters:
    database_host: 127.0.0.1
    database_port: null
    database_name: CORE_SERVER
    database_user: user
    database_password: password
    mailer_transport: smtp
    mailer_host: 127.0.0.1
    mailer_user: null
    mailer_password: null
    secret: a585529c25dadcd56170bc9a6ac1722021fadc19
```

Drawing xvii: parameters.yml

2) Configure the entity manager in confi.yml file

```yaml
# Doctrine Configuration
# /server.tfg/app/config/config.yml
doctrine:
    dbal:
      connections:
        core_server_db:
          driver:   pdo_mysql
          host:     "%database_host%"
          port:     "%database_port%"
          dbname:   "%database_name%"
          user:     "%database_user%"
          password: "%database_password%"
          charset:  UTF8
```

Drawing xviii: config.yml

3) Now it is time to create and map the entities for the three tables defined. This is going be done in the *EntityBundle.*The code for the entities can be seen in the ANNEX II, in the /server.tfg/src/EntityBundle/Entitiy/*.

Once we have defined each class, its attributes and the information which relates

it to the real databases tables, the following commands will do the rest (extracted from http://symfony.com/doc/current/book/doctrine.html):

```
$ php app/console doctrine:create:database
```

The above command will create the database if does not exist yet.

```
$ php app/console doctrine:generate:entities CoreServerEntityBundle/Entity
```

The above command will automatically create getter and setter methods for the three entities. Now it is only left to tell Doctrine to map the information:

```
$ php app/console doctrine:schema:update –force
```

The above command will map the information and thus, get Doctrine available to work.

3.2.3.5 Code the Controllers

The code for the three controllers can be seen in the ANNEX II as well. Note: as it can be seen, in the *DeviceController.php* class none of the HTTP interactions with the board has been implemented yet. The PHP library which is going to be used is https://github.com/kriswallsmith/buzz.

3.2 End User Application

I have also implemented a little end user application in order to be able to test the *Core Server.* The aim is not to code a full-featured home automation application but to be able to test the core server.

In this application there is only one controller that gathers all the information from the database table DEVICES_ALL and shows a list with every device, enabling you to execute the actions they are prepared for. This one can also be seen in the ANNEX II, under the name of EndAppHomeBundle.

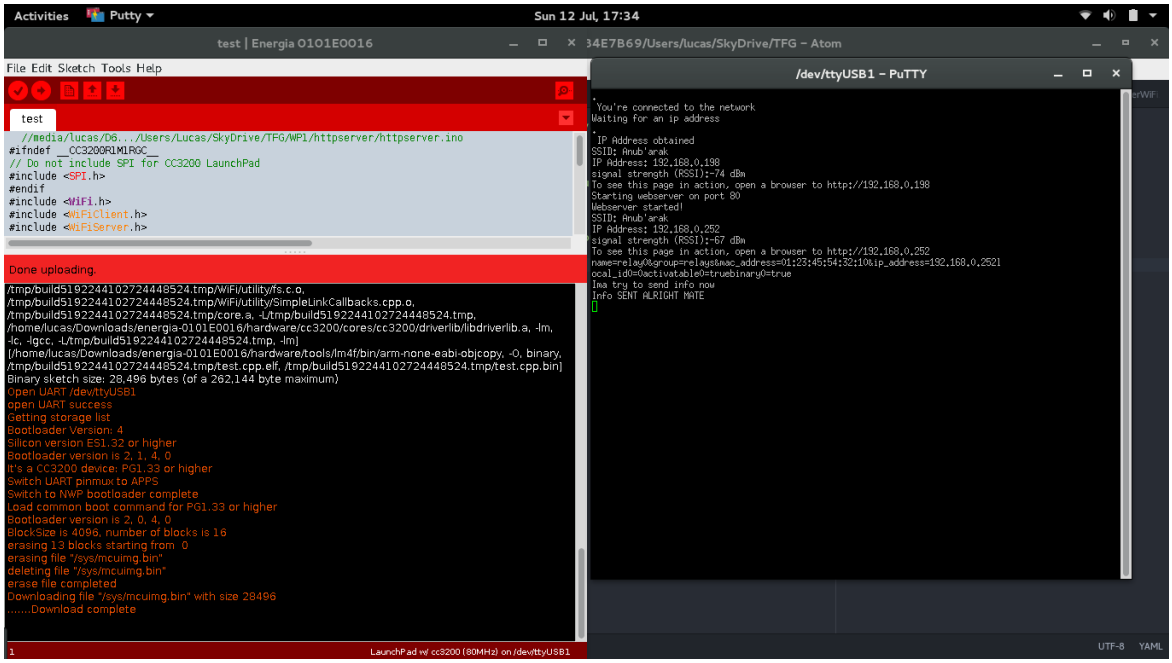
4. Results

4.1 CC3200 and Test Code

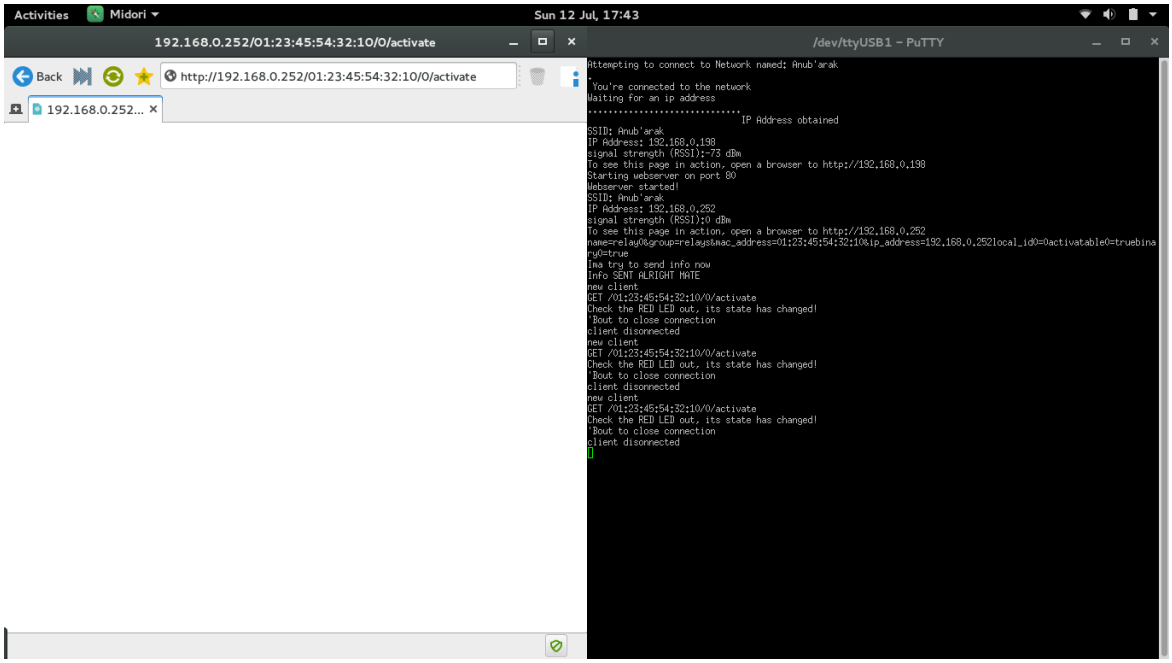
In order to test that the management of the Smart Object is achievable, I coded down a simplier Energia skecth, though fullfiling the specifications, to manage a relay connected to CC3200 Launcher Board. The code of this sketch can be found in the ANNEX III– Results.

The creation of the electronics needed to make the relay work came by the hand of my advisor Vicente.

The two following pictures come from the test. They are two screenshots where a serial port monitoring of the board's output traces can be seen. The board only responds an *ok 200* header and closes connection.



Drawing xix: cc3200 test 1



Drawing xx: cc3200 test 2

4.1 Core Server and End App

Unfortunately I didn't manage yet to achieve the self-registration of the board into the *Core Server*. I must be missing something in the Symfony enviroment.

Despite of that, the basic internal functionalities of the implementation are tested, as the code is been created from former projects I've been involved in.

5. Budget

This project has got cost 0. All the material used has been borrowed to the ETSETB Electronical Engineering department.

5.1 Components list

The material borrowed for prototyping is:

- Texas Instruments, CC3200 LAUNCHERXL
- TE Connectivity Potter & Brumfield Relays, OJE-SS-105HM,000

5.2 Design cost

This project developement, the design and the implementation of the code has taken for me about 10 hours/week during 20 weeks, resulting in a spent time of 200 hours approximately.

5.3 Financial viability

The first thing that must be reminded is that this project is fed, and also shares, the FOSS fundamentals. Thus, its aim is not to make economical benefit out of it, but to give society a tool to be used in IoT and Home Automation enviroments.

The main distributing source shall be *GitHub,* and try to *fork* the Symfony to code a less-featured and more dedicated framework for this funciontalities.

6. Conclusions and future developement

Every day the world of technology evolves amizingly fast. The IoT term, web services, content delivery networks. All of this terms come to aim the same thing, to develop tools that lets people in general to be more productive and more efficient. To share resources among all the of the desired machines, devices, smartphones and, eventually, users. The BigData also tries to embrace the management of the huge loads of information produced every hour.

I do really believe that the network will eventually become a single application, more like a global operating system than a network itself. The compatibleness among coding languages, the APIs written for almost any need will, in my opinion, someday reach a global application. That vision of the future (or even present) is stuning. The way I see non developer users integrate technology in their lifes, the way new applications are developed in a blink of an eye, is half scaring half amazing. I do not know if people is prepared for a world where any information is reachable in the click of a mouse, all of the devices reachable, every single person identified. As humaninty is not predictible, we can only wait and see what happens.

In this project, I propose a manner to try to integrate IoT with HTTP, and thus, enable any developer to use that infraestructure to manage smart objects. I do not actually know if it is a good system, or if someday me and my uncle will deploy it to use it in a real Home Automation application, but at least I touch the critical parts of what I consider the new paradigms nowadays. Doing a smooth benchmarking, I noticed that what manufacturers are doing is exactly that, to convert the analog data that a low-level device produces, process it and send it to the world as standarized as possible. That, for a person with pesimistic tendencies like, takes me to think that this project is just a waste of time, as long as I bet that some standard solution must appear in the near future.

I say that beacause I do really believe there is a need to cover in IoT. There are a lot of ways of having lots of IoT devices managed by an Arduino, but there is not yet a way to be able to manage all of this straight in the application layer. If that would come to happen, and hopefully would be done via this project, that solution shall rise from the community, thus using open-source resources, just like PHP. If any device would come to meet my requirements (among many other standars they actually implement), it would be an open-source alternative to manage them. I would love to also use as distributing platform services like GitHub, where anyone can fork a project and try to improve it with his own ideas. That should happen with this, as long as there is a lot of talent out there, while the basic idea is presented in this project, implementation improvements and changes could be reach by other developers.

For example, the security issue has not been treated at all. Some sort of asymetric encryption system shall be included both in the board an the server, apart from https for example. Symfony is really secure when well programmed but that is only between the end user and the *Core Server*, there is an important lack in this field when talking about the *SmartObject-CoreServer* communications.

Bibliography

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[2] http://www.ics.uci.edu/~fielding/pubs/dissertation/top.htm, Architectural Styles and the Design of Network-based Software Architectures, Roy Thomas Fielding, 2000.