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Scalable Interconnected Home Automation System

Valentin Stangaciu, Vlad Opârlescu, Petra Csereoka, Răzvan D. Cioargă, Mihai V. Micea
Politehnica University of Timișoara – Computers and Information Technology Department
Timișoara, Romania
valentin.stangaciu@cs.upt.ro, vlad.oparlescu@gmail.com, petra.csereoka@gmail.com, razvan.cioarga@cs.upt.ro, mihai.micea@cs.upt.ro

***Abstract*—Home Automation Systems have been continuously evolving in the past few years: some of the systems are focusing their attention on providing remote access and control of the system, while others are more focused on the interconnectivity of the devices and on integrating them into greater systems, like smart cities. In this paper we propose a hierarchical architecture for Home Automation Systems, which aims at integrating both approaches. We propose a modular and scalable system, with multiple layers, each layer having its own distinct structure, functionality and challenges.**

Keywords—internet of things (IoT); wireless sensor network; home automation system.

I. Introduction

More and more people choose to leave behind their traditional desktop computers and connect to the world using small gadgets like mobile smartphones, tablets and smartwatches. The demand for smart homes and environments is increasing and we are slowly entering the era of the Internet of Things. Sensor network and cloud computing technologies will need to rise to meet the new challenges, as more and more, small embedded systems start collaborating to enhance our everyday life.

Throughout the years, the concept of Internet of Things (IoT) evolved significantly including an ever increasing number of applications, but the main goal remained the same: enabling computers to gather information from the world without human intervention. Today, it is aimed to develop a network of objects able to harvest information, interact with their environment and forward their knowledge for further analysis. The evolution of this fascinating field will be limited only by our own imagination.

Nowadays, more and more devices are Wireless Sensor Network (WSN) capable. They are being used in various domains such as environment monitoring, agriculture, smart cities, etc. Their main advantage is that they can be remotely controlled from far distances and can communicate with other IoT devices, making them ideal for recording, processing and transmitting data for operations like: comparing, analyzing and collecting them from across the world. With the fast growing of internet in the last decade, the potential of IoT has increased exponentially.

Smart houses can be connected with each other and share valuable data, if needed. Systems with this kind of structure can make personal decisions, based on different measurements or event detection like the measurements of the gas, temperature, humidity, movement detection through motion sensors, etc. These sensor parameters can be stored in the cloud, so that various parameters can be analyzed by the owner from anywhere and anytime. Therefore a new term appears, Home Automation Systems (HAS) with its advantages and challenges. Reduced installation costs, system scalability and easy extension, aesthetical benefits, integration of mobile devices, represent just a few of the potential benefits. On the other hand, there are challenges which still concern the scientific community. The main challenges which our proposed solution addresses are: to reduce the high cost of ownership, to offer a flexible solution and to offer a good manageability. Thus, we propose in this paper a relatively inexpensive, flexible and scalable solution for home automation.

The rest of this paper is structured as follows: Section II surveys the related work, describing some other notable solutions. In Section III we describe the general architecture of our proposed solution. In Section IV we briefly present the main functionalities of the system and we conclude our paper in Section V.

II. RELATED WORK

In the last few years, the interest for developing new Home Automation System (HAS) architectures has been continuously growing. This phenomena is mostly due to the desire of integrating the newly developed concept of IoT into HAS.

In [1] a home automation system is proposed, which employs the integration of wireless communication, mobile devices, cloud networking and power-line communication in order to provide the user with remote control over their appliances and various devices around and within their home. Another similar solution is proposed in [2], which makes use of the LabView software to remotely control the smart devices in the HAS.

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Javale et al. describe in [3] a home automation system and an Android based application, which comes to help the elder people. The system contains a hardware device acting as gateway and interface between the targeted devices and the Android powered devices used for accessing the system.

Paper [4] shows the need of extending the classical HAS architectures as the one in [3], by enhancing the communication and the mobility. It highlights the potentials of using the Hierarchical Mobile IP in this sense. This approach offers the owner an autonomous control of the appliances and devices even if he changes location or network provider, since the system is installed with IP addresses.

Another approach is presented in [5], where a hierarchical architecture for a wireless HAS is proposed. The system uses an Intel Galileo board and a router to connect a series of devices to the internet. The system also uses a web bases application to control the devices and cloud storage to store the data collected from the sensors.

Article [6] pushes the architecture development a little further by proposing a scalable general architecture for a better integration of the Internet of Things with the Cloud Computing. Basically, this architecture, called CloudThings, offers its functionalities as cloud based services.

Architectures like the one in [6] can be a bridge for even more complex systems like the one proposed in [7, 8] for smart cities.

Thus, the HAS system architectures have been in continuous development in recent years, making this systems to go beyond independent architectures, becoming parts of greater interconnected systems. Thus, HAS can interconnect with healthcare systems [9], with energy management systems [10] or smart cities, as already mentioned.

III. GENERAL ARCHITECTURE

As stated in the previous section, some of the proposed systems are focusing their attention on providing remote access and control of the system, [1, 2, 5], while others are more focused on the interconnectivity of the devices and the systems. The last ones have proposed more complex architectures, which provide access to some of the functionalities both from a public and in from a local network [3, 4, 6] .

Each approach, deals with a specific set of challenges. On one hand, controlling remote devices requires secure and fast communication between the user and the controlled device and a relatively short response time from the system. On the other hand, interconnecting different systems and gathering data from different and numerous devices raises other challenges. mong these challenges we address: cost of ownership, flexibility of the solution and good manageability, by proposing a hierarchical, scalable, configurable and relatively flexible architecture for Home Automation Systems.

In this paper we propose a hierarchical system which aims at integrating both approaches. This system has multiple layers, each layer having its own distinct structure, functionality and challenges.

A. *System Architecture*

The system architecture consists of several layers (Fig. 2):

Layer 0 is represented by simple or smart devices, called IoT devices or nodes, which are capable of wireless communication (radio based or WiFi). The devices have the task to collect information regarding the outside environment through various sensors (e.g., temperature sensors) and send the data to the CPU to be processed. After that, the data is being transmitted to the next level: the IoT hub. Each device has associated a unique ID to be identified by the hub.

Layer 1 is represented by the hubs, which connect sets of devices from the previous level. Because we want our system to integrate both smart complex devices and small cheap sensors, we use a device called IoT hub to act as a gateway and a first level data concentrator for the connected devices. In the current implementation the IoT hub is represented by a Raspberry Pi 2 together with some communications modules for both radio and WiFi communication. One of the roles of this device is to gather data from a set of devices which are connected to it and to forward this data to the local server. In this way we can connect both devices which have and do not have Ethernet communications capabilities. Another role of this device is to make the devices transparent to the next levels. The next level sees the hub as one smart device/node with multiple sensors and capabilities (see Fig. 1).

Layer 2 is represented by the local server. This server gathers the information from all the IoT hubs from its local network, processes the data locally and offers a set of services to the user, which can connect to it both from the local network and from the internet via a web interface. This approach offers the possibility to configure and use the system both in on-line mode (with internet connection) and in offline mode, thus reducing unnecessary costs when the user accesses the system from home.

Layer 3 is represented by a public/private cloud server. This third layer offers the possibility to interconnect more systems of this kind or to interconnect this system to another type of system (e.g. other health systems). In the same time this approach can offer possibilities to different authorities to gather statistical data from different systems and from different locations.

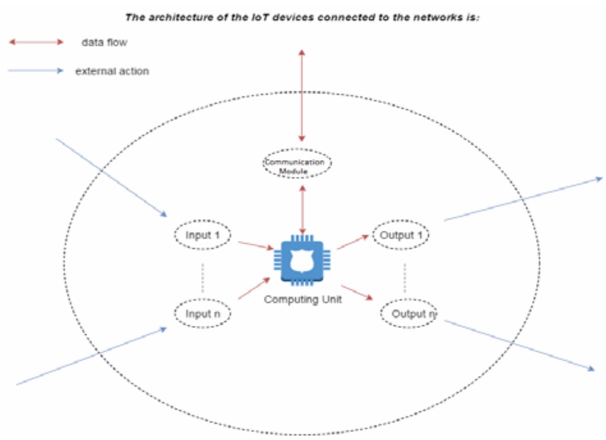

Fig. 1. Genral System Architecture

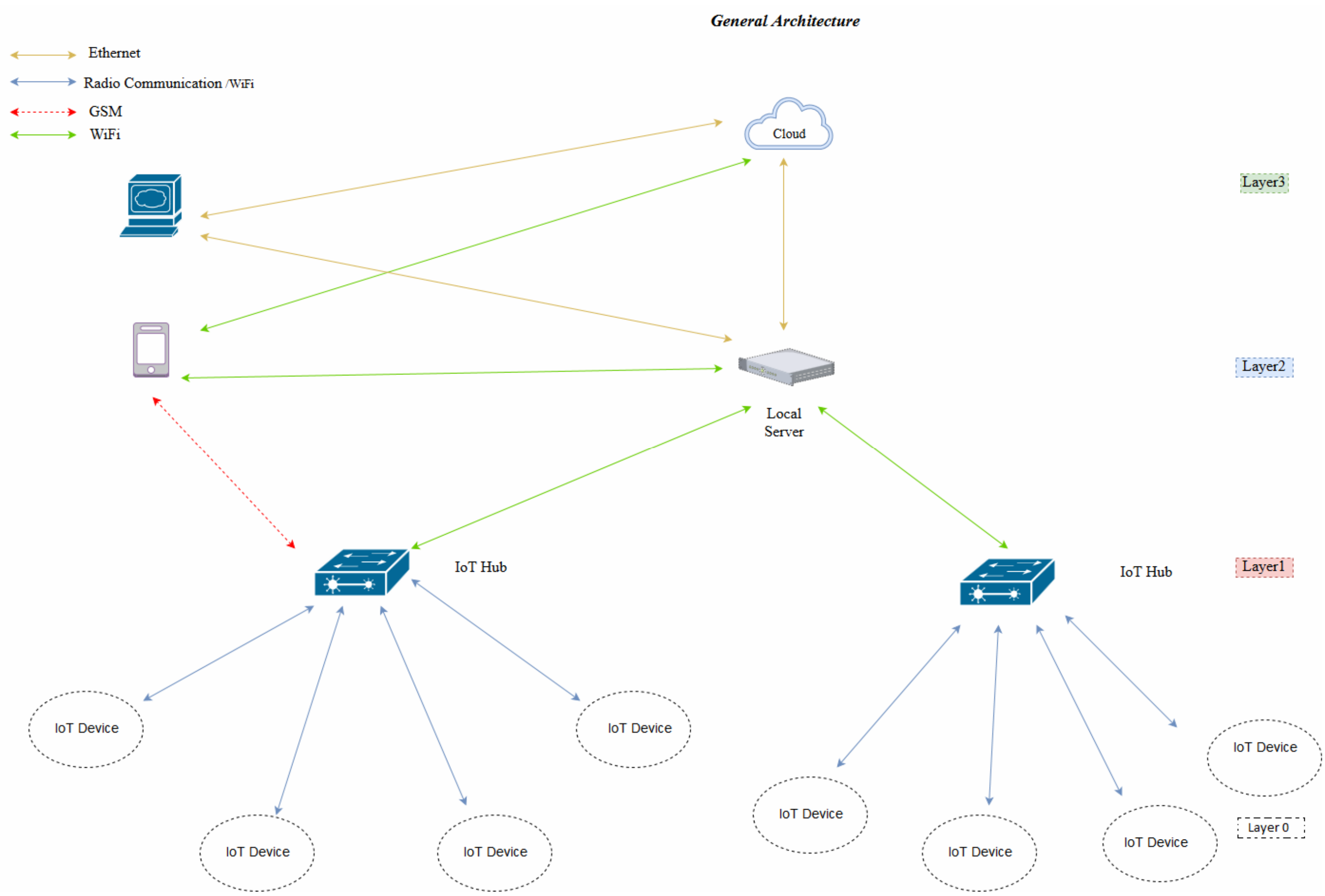

Fig. 2. General System Architecture

This layered approach makes the architecture scalable: more devices can connect to a hub, more hubs can connect to a local server and more local servers can connect to a cloud server.

The communication between layers is represented mostly by various wireless protocols as it can be seen in the same Fig. 2.

B. *Software System Components*

For each level there is a dedicated software system component (see Fig. 6).

For the Layer 0 we have the embedded software, which runs directly on each device and which is responsible for gathering data from sensors and/or receiving commands from the hub.

For the Layer 1 we have the software component which runs on the IoT hub and has the following functionalities: to discover and to add new devices to the system, to get the data from the connected devices and store it into a local database (Fig. 3 and Fig. 4) and to periodically forward sets of data to the local server. The flowchart of this application can be seen in Fig. 3.

The Layer 1 component has also the role to send emergency messages directly to the user via GSM. In this way the messages arrive relatively fast informing the user about critical events and situations.

The Layer 2 component is represented by a web based server application which allows direct connection with the user. Through this application, the user can control different devices, can visualize and analyze the data received from different sensors or devices.

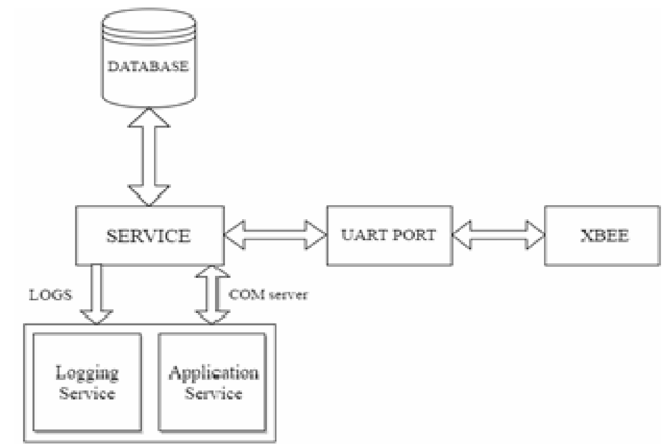

Fig. 3. General Node Architecture

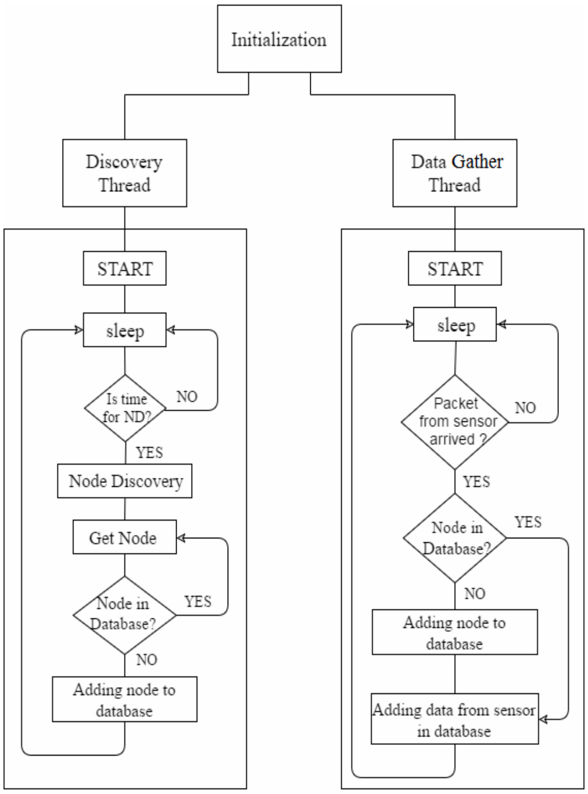

Fig. 4. General Node Architecture

The Layer 3 component is represented by the extra services which bring intelligence and interconnectivity to the system. Examples of such services can be an energy consumption analysis and prediction services (e.g. based on Azure Machine Learning) or a service which gathers data from different sources and presents statistical information and graphs (e.g. about the energy consumed in a city). With the help of cloud servers, users can access, from anywhere in the world, complex services using small amount of local resources.

Between the software components described in the previous section data packets are transmitted. In order to treat devices in a unitary way, regardless of their type we propose the following:

- IoT devices can contain more sensors and each sensor is characterized by: a unique ID, a type, a location and a measurement unit. This data is stored on the corresponding IoT hub and it is added into the hub local database, when a new device is detected and configured.
- Each device sends measurements from each of its sensors containing the unique sensor ID and the measured value.
- Each IoT hub gathers the data from its corresponding devices, adds other data like timestamps, measurement unit, etc. and forwards them at periodical intervals to the local server.

IV. Main Functionalities

The system architecture that we propose in this paper has a modular architecture, which provides a set of functionalities. Each functionality is covered by one or more devices. The proposed system is currently in development. Until now, we have developed a series of functionalities, which are described in the following paragraphs.

A. *eHEALTH*

Wearables can greatly enhance the life quality of their owners, especially when it comes to elderly people.

The wearable we propose consists of an accelerometer used to detect sudden or severe falls, a panic button to signal any kind of problems and a pulse monitoring system to signal a wide range of health issues (Fig. 5). If immediate assistance is required, either as a result of pressing the panic button or as a result of a sudden fall detection, a message to the responsible people is sent via GSM and the victims are informed if help is on the way. These components are incorporated in a small, comfortable wearable worn around the arm.

We define a fall as a sudden increase or decrease in the accelerometer's value and a change in at least one of the axis. As the elderly do not move in a rapid fashion as young people do, this sudden increase or decrease will be significant indicating an impact.

B. *House Monitoring*

Emergencies inside our homes may occur at any time, therefore installing small alarms for gas leaks and fire detection mechanisms are what we propose as a starting point. These mechanisms need to be flexible enough to allow announcing the owner in different ways via an alarm bell, SMS, email etc. [6]

Furthermore, we desire to enhance the interaction with the environment. We propose the use of intelligent sockets (Fig. 7) that can be controlled using mobile devices [10]. Now, we are able to turn on/off different power sources: turning on the coffee machine, starting the washing machine, heating the oven etc. on our way home from work or while on trips to ensure that everything functions as intended.

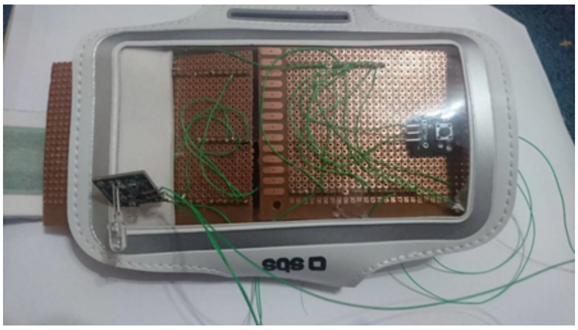

Fig. 5. Wearable

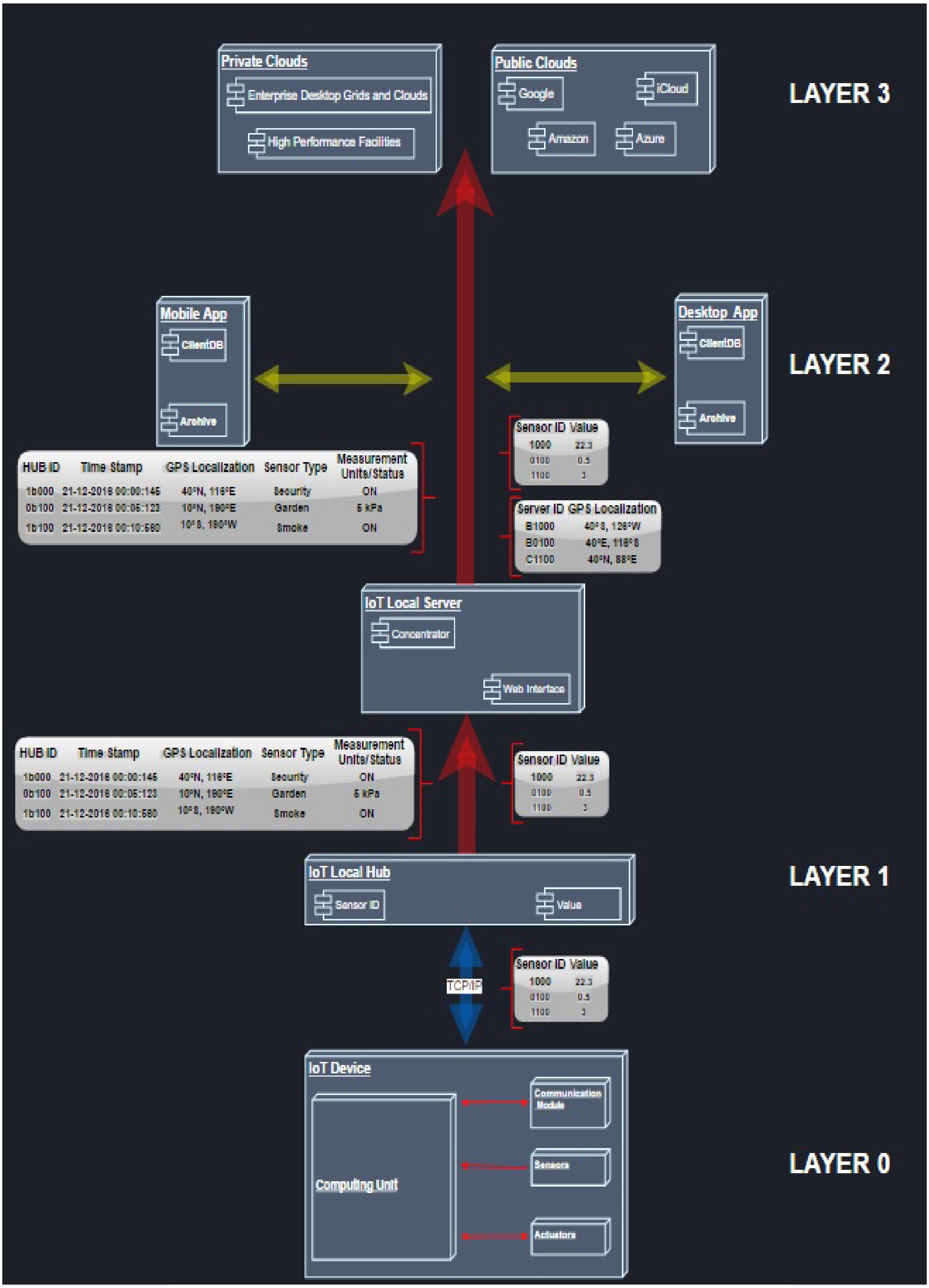

Fig. 6. Data Flow between System Components

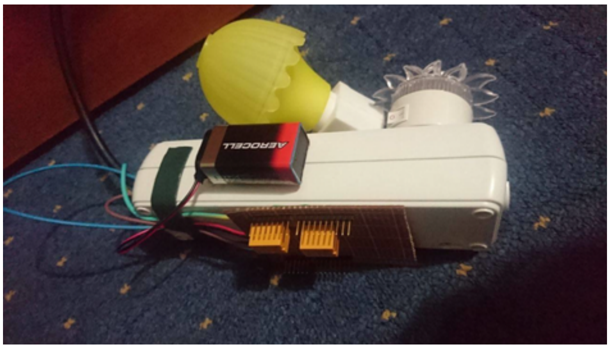

Fig. 7. Intelligemt socket

C. Garden Monitoring

An easily configurable and autonomous garden monitoring system can be installed with very little effort in any household, bringing numerous advantages.

The proposed system is able to auto-schedule the irrigation time with respect to the season, by using a calendar. In addition, in order to optimize the resource consumption (water and power) and to avoid plant harming (watering at the wrong moment of the day, over/under watering) we use temperature and humidity sensors to decide the optimal course of action. Each irrigation pump will be controlled by its own relay. The user has the possibility to design its own scheduling if the type of the plants is changed (their watering needs might change as well).

D. Entertainment System

As entertainment plays an important role in our everyday lives, we have included an entertainment module capable of browsing through the owner's movies, music and different shows, gathering different information about them such as director, actors and reviews, and stream those movies to the available mobile devices, smart TVs and streaming boxes.

This application also provides the possibility to organize your audio and video content into configurable libraries. Additionally, integrated channels can provide users with access to different online resources located on YouTube, CNN, Ted Talks etc. Interfacing with cloud services will also be provided, and especially access to Dropbox and Google Drive.

In order to integrate this functionality into our modular, layered architecture we have added a Plex Media Server [11] instance on the local server and a Plex Media Client [11] on the IoT hub. In this way the smart TV, which is a layer 0 device connects to the service via the IoT hub, which is a Layer 1 device.

V. CONCLUSIONS AND FUTURE WORK

In this article we have proposed a layered architecture for Home Automation Systems. The proposed architecture offers the advantages of being modular, scalable and in the same time the system can be interconnected to other systems via Cloud Server (Layer 3).

This layered approach offers a good data and functionality separation and most of all it allows the system to treat different devices in a similar manner.

This system is currently in development, thus we propose for future work to continue with the implementation, by adding different functionalities, mostly at the local and the cloud server layers.

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