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Automatic Integration of IoT Devices

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Abstract

During the last years a new concept has gained prominence in the technology world. With an increasingly dominant role in our days, Internet of Things (IoT) is a technological revolution that is changing our lives. The imagination is the limit for the new devices that may appear in the market. This phenomenon is derived from both, the technological evolution and the growing acceptance of this type of products in our social life. Faced with a fast growth, an increasing diversity and with the existing uncertainty about the new devices emerging in the market, there is a need to integrate each new device in our lives. However, nowadays, there is no existing structure prepared for the actual diversity in IoT world.

Applications that integrate devices from many different vendors are now available, but these rely on manual configuration by the application developers for every new device integrated, which is tedious and requires application updates to be rolled out frequently. An application that can discover the new device properties, and decide to which class of devices it belongs to can automatically generate an interface and the necessary integration drivers for the new device with no/less human intervention. This is the main direction of this works' contribution.

To achieve this goal we need to identify the device that is communicating inside a network using the information shared by IoT devices. The final results show that IoT communication data can be used to identify the device, mainly if in possession of a considerable sized device information database.

Keywords: Internet of Things, Integration, Discovery, Device

Resumo

Durante os últimos anos um novo conceito ganhou destaque no mundo da tecnologia. Com um papel cada vez mais dominante nos nossos dias, IoT é uma revolução tecnológica que está a mudar as nossas vidas. A imaginação é o limite em relação aos novos dispositivos que surgem no mercado. Este fenómeno é impulsionado pela evolução da tecnologia e crescente aceitação deste tipo de produtos no nosso dia a dia. Perante tal diversidade, crescimento e com a incerteza existente sobre os novos dispositivos emergentes no mercado, existe a necessidade de integrar cada novo dispositivo nas nossas vidas. No entanto, hoje em dia, não existe uma estrutura preparada para a actual diversidade existente dentro do mundo da IoT.

Actualmente já existem aplicações para integrar dispositivos de diferentes fabricantes, mas estão dependentes de uma configuração manual por parte dos programadores para cada novo dispositivo integrado, o que é trabalhoso e exige o lançamento de atualizações com frequência. Uma aplicação que consiga descobrir as novas propriedades do dispositivo e decidir a que classe de dispositivos pertence, pode gerar automaticamente uma interface e os controladores de integração necessários para o novo dispositivo com menor, ou mesmo sem qualquer intervenção humana. Este é o ponto principal da contribuição deste trabalho.

Para atingir esse objetivo é necessário identificar o dispositivo que está a comunicar dentro de uma rede utilizando as informações compartilhadas pelos mesmos. Os resultados finais mostram que os dados de comunicação podem ser usados para identificar o dispositivo, principalmente se existir uma base de dados de informações de dispositivos IoT de tamanho considerável.

Palavras chave: Internet of Things, Integração, Procura, Dispositivo

List of Acronyms

3G Third Generation.

4G Fourth Generation.

API Application Programming Interface.

CES Consumer Electronics Show.

DSL Digital Subscriber Line.

GSM Global System for Mobile Communications.

HSPA High Speed Packet Access.

IDE Integrated Development Environment.

IEEE Institute of Electrical and Electronics Engineers.

iOS Iphone Operating System.

IoT Internet of Things.

IP Internet Protocol.

ITU International Telecommunication Union.

JSON JavaScript Object Notation.

MAC Media Access Control.

NFC Near Field Communication.

OUI Organizationally Unique Identifier.

QRCODE Quick Response Code.

RFID Radio Frequency Identification.

SSL Secure Socket Layer.

TF-IDF Term Frequency – Inverse Document Frequency.

URI Uniform Resource Identifier.

URL Uniform Resource Locator.

WIFI Wireless Fidelity.

XML eXtensible Markup Language.

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Chapter 1

Introduction

1.1 Goals

During the last years a new concept has gained prominence in the technology world. With an increasingly dominant role in our days, IoT is a technological revolution that is changing our lives. This concept is derived from the current set of existing devices on the market that have the property of being able to connect to the internet and share information. This type of device is used nowadays in different situations.

There are more smart devices appearing each day, this phenomenon is derived from technology evolution and the growing acceptance of this type of products in our social life. The imagination is the limit regarding the new devices that may arise in the market. Faced with such diversity and with the existing uncertainty about the new devices emerging in the market, there is a need to integrate each new device in our lives.

Each device has its way of functioning, but there is a common feature in all: these devices must have the ability to communicate. This communication may be made through various communication protocols, however, the aim is always the sending / receiving of data between devices and the ability to communicate in the

same protocol. To make this happen it is necessary to establish this connection, which involves some settings such as the authentication process.

What if there was a way to automate or facilitate this integration? Is it possible through the information generated by the device to discover what type of device that is, what steps are necessary to establish communication, and how to integrate it seamlessly in our own application's device catalog? The aim of this thesis work is to identify and study the communication of the different devices on the market. It is also an objective to search through device information in order to create ways to automate the integration of any new device.

To conclude, this study aims to answer two fundamental questions: Can we ease or even automate the integration of new devices on a home network control application? Can this automation be applied on top of an existent device integration platform?

1.2 Motivation

The number of devices on the market within the scope of IoT has experienced exponential growth. This technology sector is booming and will increasingly be part of our days. It is therefore essential that the configuration of these devices become the easiest possible to the end user and to the application developers.

One of the main goals of this work, is to contribute to the discovery new techniques that may ease the identification and integration of new devices found in a network. These techniques may be very important to the development of more advanced integration systems inside IoT area which is, of course, constantly evolving. With this work we create the possibility to facilitate the use of these devices even for people with little know-how on this matter. This possibility brings additional motivation because it can mean an easier integration of IoT devices for the final user.

1.3 Methodology

The methodical approach that is applied in this thesis is design science research. The design science research purpose is to solve practical and theoretical problems. Two paradigms characterize much of the research in the Information Systems discipline: behavioral science and design science. In the understanding of [von Alan et al., 2004] while the behavioral- science paradigm seeks to develop and verify theories that explain or predict human or organizational behavior, the design-science paradigm seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts.

In this thesis, the entry point to the design science research method will be an existing problem. This way, taking into account the design science research phases specified by [Peffers et al., 2007], there is a need to determine the actual problem (1st phase) and what we propose to solve it (2nd phase) followed by the 4 remaining phases (Design & Development, Demonstration, Evaluation and Communication):

Regarding this work it's also important to follow with care each of the 7 defined guidelines:

- **Guideline 1 - Design as an Artifact:** This work will produce a prototype that provides an example of this automation technique.
- **Guideline 2 - Problem Relevance:** The problem is well defined and is very relevant in IoT word.
- **Guideline 3 - Design Evaluation:** When finished, the prototype will be evaluated by testing the integration of unknown devices given a set of known devices.
- **Guideline 4 - Research Contributions:** The research must provide clear and verifiable contributions in the areas of the design artifact.

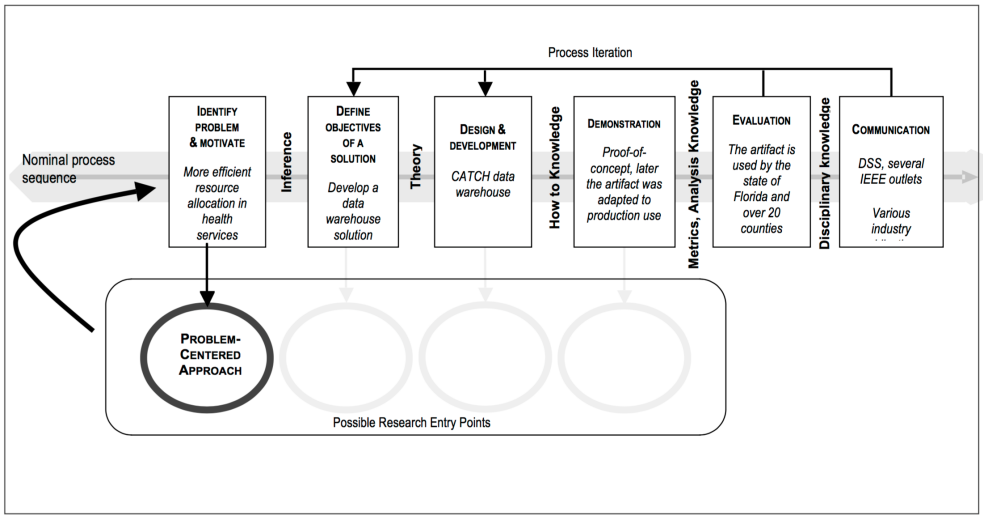

Figure 1.1: DSRM Process Phases

Source: Peffers et al. [2007]

- **Guideline 5 - Research Rigor:** Scientific rigor will be applied on every research stages.
- **Guideline 6 - Design as a Search Process:** Reliable information will be used on the development of the prototype.
- **Guideline 7 - Communication of Research:** It will be present an article.

To prove the concept proposed on this thesis a mobile application was developed. Initially, this app will receive and import communication data from IoT devices to generate a device information database. Finally, when the database is built, the app can receive a new communication file and, based on some techniques used in this work, it will return the type and the most similar device. The techniques used are the Levenshtein Distance algorithm, Term Frequency – Inverse Document Frequency (TF-IDF) tables, Synonyms match, and Multi-Property matching, all with the same purpose: to identify similarities between the proprieties of IoT communication data.

1.4 Scheduling

This work was done according to the following scheduling plans:

- **Appendix A:** Original scheduling plan
- **Appendix B:** Real scheduling plan
- **Appendix C:** Gantt Chart

1.5 Document Structure

The present thesis consists of 5 chapters, structured as follows:

- Chapter 1 presents an introduction for this work explaining the Goals and Motivation about this subject, the methodology used and the scheduling plan.
- Chapter 2 starts by explaining the IoT definition. After which it focuses on some important points about IoT architecture and the existing platforms. On the final part, we exemplify some IoT applications, talk about the challenges that IoT will face in future and how a good part of these challenges are related to this research.
- On Chapter 3 we can find a description of the prototype made. It details the app development process, describes the import data phase and explains each algorithm used on our tests.
- Chapter 4 is dedicated to the presentation of the results obtained. This chapter is divided in sub-sections for each algorithm used on tests.
- Finally, Chapter 5 presents the conclusions and future work.

Chapter 2

State of the Art

This chapter is divided into three main sections. The first part briefly introduces the definition of Internet of Things. The second and third parts focus on the IoT architecture, illustrating the system platforms and protocols and describing each connection mode. The fourth part presents multiple IoT applications in different areas. The last section describes the current IoT challenges.

After a deep search through the Internet we were unable to find any work related to automated device discovery, therefore, we will detail the most important IoT communication aspects.

2.1 Internet of Things

2.1.1 Definition

The definition of Internet of Things (IoT) is not fully consensual among different organizations and authors. Some examples of definitions show just that:

”The basic idea of the IoT is that virtually every physical thing in this world

can also become a computer that is connected to the Internet (International Telecommunication Union (ITU), 2005). To be more accurate, things do not turn into computers, but they can feature tiny computers. When they do so, they are often called smart things, because they can act smarter than things that have not been tagged"[Fleisch, 2010].

"A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies" [I T U, 2012].

"The Internet of Things (IoT) is the network of physical objects accessed through the Internet, as defined by technology analysts and visionaries. These objects contain embedded technology to interact with internal states or the external environment. In other words, when objects can sense and communicate, it changes how and where decisions are made, and who makes them" [Systems, 2012].

"a pervasive and ubiquitous network which enables monitoring and control of the physical environment by collecting, processing, and analyzing the data generated by sensors or smart objects."[Systems, 2012].

However there are some important aspects that help define better this expression. Starting by analyzing the name, "Internet of Things" is syntactically speaking, formed by the two terms "Internet" and "Things". The first term shows the instrument under which the IoT works and one of the reasons for such a success, the emergence of this phenomenon was only possible due to the already existence of another major phenomenon, the Internet. It is also through the power of the Internet that all objects can communicate with each other and thus provide all its advantages. This statement leads us to the second term , the "Things", which according to ITU "is an object of the physical world (physical things) or the infor-

mation world (virtual things), Which is capable of being identified and integrated into communication networks" [I T U, 2012] . The "Things" are any object with a unique and identifiable ID that generates some kind of information and can then share that information over the internet. The definition of this term is more easily understood if we check the purposes of Internet of Things.

2.1.2 IoT Purpose

The purpose of the Internet of Things can be summarized to three important aspects. The first goal is to transform the objects in connectable objects or smart objects providing them with some intelligence and the means to allow them to share their own information. For this to be accomplished it is necessary to integrate the hardware that will make it possible for the object to communicate with any platform. In the next chapter we will detail the various ways of doing this. Due to miniaturization, it is possible nowadays to place this type of hardware even in the smallest of places, allowing its inclusion in all kinds of objects. This miniaturization allows the IoT to reach more and more applications where it was not possible in past.

Another important goal is to create the necessary conditions for these objects to communicate with each other (within the same network) and globally (Internet), allowing, through synergies, to add even more value to the information obtained. This communication is one of the main challenges of IoT nowadays, given the diversity of objects, platforms (Iotivity, HomeKit, AllJoyn ..) and methods of communication (WiFi, Bluetooth ..). The growth in the number of existing objects is increasing the amount of data generated and the main goal will be to explore well this information and make all efforts to get various benefits through the IoT world.

2.1.3 Growth of the IoT

The term Internet of Things makes its first appearance in a presentation made in 1999 about Radio Frequency Identification (RFID) [Ashton, 2009].

Fifteen years go by and, as we see in the following figure, the number of existing IoT devices never stopped growing and has even surpassed the number of existing people on the planet in 2008. In last years the number of new devices has grown exponentially and if today we have 15 billion devices, in 2020 it is anticipated that there will be 50 billion devices worldwide, about 6 per person.

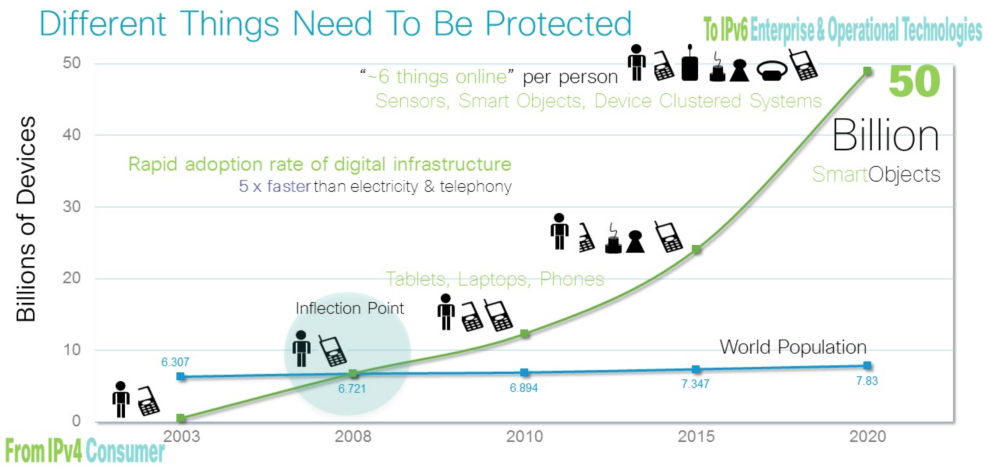

Figure 2.1: IoT growth over the world population

This growth is mainly due to technological development that allowed the miniaturization of hardware and the reduce of material costs. Another reason is the ”hype” that we can verify with the increasing marketing around these products, using the word ”smart”. These are indeed incredible numbers that make us wonder if the structures used today are really prepared for this growth or at least if we are on the right track.

2.2 IoT Architecture

The architecture on Internet of Things (IoT) can be summarized by four functional layers: the interaction layer, the representation layer, the service layer, and the application layer.

The Interaction Layer is formed by the connected devices. On this layer are included all the hardware pieces physically attached to an object that enables its communication with other devices and the Internet. This layer allows the interaction of the objects with the real world and the information generated therefrom is sent to the upper layer.

The next layer (Representation Layer) is responsible for managing each of the objects, providing an identification method (e.g. the Uniform Resource Identifier (URI) / Uniform Resource Locator (URL)) and a way of establishing communication with each object using its own methods. This layer makes possible to the objects the Exchange of information with each other and with the outside world (Internet), allowing its use by the top layer.

The Service Layer works over the Representation Layer to provide the functionality and information from all the objects connected. This layer will allow users or programmers to use this information in a standardized way.

Finally, the Application Layer is formed by many types of applications where the features and the information provided by the Service Layer are consumed.

2.2.1 Connection Modes

There are several communication modes that allow objects to receive and send information. Each type of communication has its advantages and disadvantages and objects can choose one or more types of communication regarding its features and goal.

The Connection modes can be one of four types: Connection on demand, Connection when within range, Permanent wireless connection and Permanent wired connection.

The ”Connection on demand” type involves user interaction, and is typically used in cases where the exchange of information is needed only in the presence of the user. As examples, the Quick Response Code (QRCODE), Smart Card or RFID.

The type ”Connection when within range” requires proximity between the two parties. This type of communication is only possible when the two objects are close enough and it is used on objects that do not require a continuous flawless communication. The Bluetooth and the Near Field Communication (NFC) are examples of this type of communication.

Finally, within the ”Permanent connection” we have the Wireless and Wired connection types. These two types are distinguished by the need of physical connection (via cable). Examples of wireless connections are the Third Generation (3G), the Wireless Fidelity (WIFI), Z-Wave and ZigBee. Finally as examples to cable connection we have the Digital Subscriber Line (DSL) or optical fiber (Ethernet).

2.2.2 Communication Protocols

In this section we will detail the most commonly used communication protocols inside the IoT world. The existence of many distinct protocols is directly related to the different requirements of the devices inside their own purpose. Besides the various connection modes that we define on subsection 2.2.1 other necessities like required bandwidth or energy consumption limitation opens space for this distinct ways to transport data. With no specific order, the following communication protocols are the most widely used nowadays on IoT:

- **Bluetooth**: created by Ericsson company in 1994 [Haartsen, 1998], Bluetooth is still one of the most used protocols. It is a short range communication technology that start to gain popularity by the exponential adoption on mobile devices on late 90's. It is a wireless protocol, initially based on Institute of Electrical and Electronics Engineers (IEEE) 802.15.1 that works on 2.4Ghz frequency and have a maximum range of 150 meters. Since the creation of the specification on 1998, there have been released several versions with many enhancements like faster connection and lower energy consumption to save battery power in mobile devices. The last version 5.0 was announced in June 2016 and the enhancements are mainly focused on Internet of Things emerging technology. This is a important sign that this protocol will continue to be adopted on IoT devices that needs this specific characteristics of Bluetooth communication.

- **Zigbee**: this is a wireless protocol based on IEEE 802.15.4 specification and works on different radio bands depending on each country jurisdiction (868 MHz in Europe). It was developed by Zigbee Alliance [Kinney et al., 2003] in 1998 with the target of low energy consumption and applications monitoring with use of different kind of sensors. Zigbee protocol main use is low sized data transfers where it is more efficient than other protocols (e.g. Bluetooth). This protocol is completely settled on IoT world with the most recent version Zigbee 3.0 [Alliance, 2015a] promising even easier communication and interoperability among devices.

- **Z-Wave**: developed with an explicit focus on home control applications [Reinisch et al., 2007] Z-Wave is a wireless protocol based on ITU-T G.9959 specification and it's purpose is to provide a faster and simpler development by using a simpler protocol (comparing with others like Zigbee). It is optimized for reliable and low-latency communication of small data packets

with data rates that can reach 100kbit/s (vs 250kbit/s of Zigbee or 1Mb/s on Bluetooth) and is capable of communicate with a maximum distance of 30 meters. This protocol was created by Z-Wave Alliance [Alliance, 2015b] in 2005.

- **Ethernet**: this is a wired connection type protocol. It is based on IEEE 802.3 specification and it was first standardized on 1983 [CarlSSon, 2003]. Since it requires physical connection it is only used on very specific situations like high security demands. The last standard release was IEEE 802.3bz on September 2016 and the data throughput can reach up to 5 Gbit/s.

- **WiFi**: created on 1997, this is probably the most well known protocol. WIFI comes from the words "wireless fidelity" [Lee et al., 2007] and is based on IEEE 802.11 specification. This protocol is by no means specific to IoT use, however many manufacturers choose this protocol because it's a very well settled protocol and due to the need of high data transfers. Besides 2.4 Ghz communication on first versions, the most recent IEEE 802.11 ac specification uses 5.0 Ghz that allows a maximum throughput of 1.33 Gb/s maintaining a maximum range of 70 meters. This protocol uses more energy power due to its range and high data transfer capacities.

- **Cellular**: IoT applications that need to operate over longer distances can take advantage of Global System for Mobile Communications (GSM), 3G or Fourth Generation (4G) cellular communication protocol. GSM was released back in 1991 [Liikanen et al., 2004] and, most recently 4G LTE was released on 2009 [Huang et al., 2012]. The main use of this protocols is the wireless mobile telecommunications and, for that reason, the range is very large reaching from 35 kilometers on GSM to 200 kilometers on High

Speed Packet Access (HSPA). In this case the energy consumption can vary between low to very high demands depending on the amount of data to send/receive. The data throughput can reach up to 100 Mb/s on 4G communication and the radio frequencies used depends on each country (900, 1800, 1900 and 2100 MHz are the most used worldwide).

- **NFC**: this is a protocol based on ISO/IEC 18000-3 standard and it was has been developed jointly between NXP Semiconductors and Sony Corporation [Curran et al., 2012]. NFC has the objective of allow easy and safe two-way interactions between electronic devices like smartphones. One example of usage is the contact-less payment transactions. This protocol uses 13.56 MHz radio frequency and have a maximum data throughput of 420 kb/s. There is two of communication: active and passive. On active mode both devices uses electric fields where in case of passive mode only one needs to generate electric field. The range is cut to only 10 centimeters and the power consumption is minimal compared to Bluetooth or even Zigbee.

2.2.3 MAC Address Discovery

The IoT devices contain a specific piece of hardware (Network Interface) that is responsible for establishing a connection. Each one of them are labeled with a unique identifier that is called Media Access Control (MAC) address. These addresses are formed according to the rules of specific standards managed by IEEE. Part of this address is reserved for the Organizationally Unique Identifier (OUI) that allows the association of MAC addresses to a specific company. Any device can see the MAC addresses and respective Internet Protocol (IP) of other devices inside the same network. With this mac address we can discover which company the device belongs by reading the included OUI . However, this information is

very poor because it only gives us the name of the company and sometimes no organization is associated with the MAC address received. In most of the cases, one company produces many different devices that will have the same OUI, thereby preventing the use of this technique for device discovery. One example of a software capable of doing this is Wireshark [Wireshark, 2016].

2.3 Platforms

In this chapter we will present a brief summary of each of the actual major 4 IoT platforms in the market.

2.3.1 AllJoyn

AllJoyn is a open source Application Programming Interface (API) that provides a simple work environment for the IoT objects. Initially developed by Qualcomm Innovation Center, Inc the AllJoyn project is now on the hands of AllSeen Alliance. This environment allows the object to be easily discoverable and at the same time guarantees security. AllJoyn compromises to ”reduce the time, effort, and cost of adding advanced features to apps and help ensure interoperability across device types and operating systems.”[Alliance, 2015a]. There is now more than 200 companies using AllJoyn API and that can show the success of this Platform. Some other advantages of this platform include:

- Interoperable support for a wide variety of OS’s for broader reach across device types and new product categories
- Flexible, easy-to-use API framework for less time coding and more time creating

- Things in the Internet of Everything to be programmable by exposing capabilities as APIs and enabling device introspection
- Easy discovery and group formation among devices, harnessing dynamic possibilities in the proximity environment

2.3.2 IoTivity

Iotivity is an Open Source Project sponsored by the Open Interconnect Consortium (OIC) [Arseni et al., 2015] and hosted by the Linux Foundation which was founded in July 2014. Counting now with more than 50 members, the aim of this project is to develop an open source software framework to seamlessly connect the billions of devices in the emerging IoT across multiple operating systems and network protocols. This open source implementation helps to ensure interoperability among products and services regardless of maker and across multiple industries, including smart home, automotive, industrial automation, and healthcare. The IoTivity architectural goal is to create a new standard by which billions of wired and wireless devices will connect to each other and to the internet. The goal is an extensible and robust architecture that works for smart and very small devices [Foundation, 2016]. As advantages this project claims:

- Reuse existing and establish new common communication protocols for discovery and connectivity across multiple transports.
- Common approaches for security and identity.
- Device and application interoperability across markets and use cases.
- Opportunities for innovation and allow for differentiation.

2.3.3 Apple HomeKit

HomeKit, is the Apple's platform for home automation and it was introduced at the 2014 edition of the Apple Worldwide Developers Conference [Nimmermark and Larsson, 2016]. In relation to the other 3 platforms, this platform covers less devices because it is designed only to home automation use. Unlike the other platforms discussed in this work, Apple's Home Kit is not an open source framework, so you have to submit an enrollment form to join the Home Kit program. Apple has a big marketshare in the smartphone area so this platform has an initial advantage to be well succeeded. However this is not enough because the IoT world is scattered and this success is directly tied to the companies will to add Home Kit support in their devices. To Apple, the main advantage of this platform is to guarantee that home automation accessories compatible with Home Kit, can all be integrated into a single coherent whole without vendors having to coordinate directly with each other. Some advantages of this platform include:

- Many partnerships already made with many manufacturers
- Full integration with iOS devices

2.3.4 Google Brillo

Google is the latest entrant to the crowded IoT market with Google Brillo platform. Presented on Consumer Electronics Show (CES) 2016 Google Brillo is meant to make tiny IoT applications, highly efficient, very fast [Hexmoor, 2016]. This open source platform is composed by a lightweight embedded OS based on Android, core services and a developer kit. Brillo uses Google's own communication protocol (Weave) that is based on Bluetooth and WIFI together to communicate with other devices. Google is already working with hardware partners to

certify the boards that are compatible with Brillo knowing that the OS can run on low-end devices with at least 128MB of storage and 32MB of RAM. As well as Home Kit, Brillo success depends on companies adoption and their hope relies on the widely used Android that can bring some advantage on this ride.

2.4 Applications

This chapter demonstrates the variety of areas where the IoT is already implemented and future implementations that will be possible with next year's technology advances. However, with such spread of devices existing on the market and new applications appearing everyday, it is almost impossible to cover all the possible uses of IoT, so we will only detail three main applications areas:

- Smart Home
- Healthcare
- Environment

2.4.1 Smart Home

This is a special place for most people. We search for comfort, security, entertainment when we are home. So it's normal that IoT applications goes in our needs direction. There are new IoT ideas made from scratch but also normal appliances that we use each day that are "enriched" with the possibility to connect to the internet and become IoT devices. Previously we use air conditioners to acclimatize our homes and we control it with remote controls, but with IoT, these devices became connected and while we are working or arriving home we can turn it on/off. This provides the comfort of having our favorite temperature set when arriving

at home. Washing machines, Lights, Cameras are all examples of devices that already entered on the IoT world providing advantages to our lives.

2.4.2 Healthcare

Medical objects can also benefit from IoT with the acquisition of new capabilities. For example heart rate monitors or other life supporting monitors are now connected to the Internet alerting for emergencies or anomalies. Scales and Blood Pressure monitors are now ready to save historic information that can be crucial on some medical decision. Automatic scan based on sensors reading specific biometric features could save time in triage and speed the processes up by categorizing certain symptoms. Providing such objects with intelligence and autonomy can represent a big step to an increased quality of life in healthcare area.

2.4.3 Environment

The use of IoT devices can bring many advantages to the environment too. The main idea is to alert the users of their footprint, something that cannot be done before without this new devices. An example of this are the new sensors that can be placed on energy counters or even gas/water counters, we can have more control on our usages leading to a greener life. All the IoT devices can have the intelligence to auto shutoff when not in use avoiding normal human forgetfulness. Devices connected to the car already alert conductor to an efficient driving spending less fuel and releasing less pollutant emissions. If more people contribute this way, with the help of IoT devices, we can believe in a less polluted environment.

2.5 IoT Challenges

As we already discussed, IoT can bring many benefits on different application areas and new devices are emerging everyday. Still, as the evolution of the IoT takes place, there are also barriers appearing that have to be surpassed to guarantee a sustained growth. Currently IoT is facing (or will face in the future) the following challenges:

- **Security**: The simple fact that each device can send and receive information creates new security concerns. One of the main reasons for these concerns is that the devices themselves are often in vulnerable locations. Security will have to be integrated as part of IoT infrastructure because the networks where the devices communicate can't always be trusted and, in this case, each device becomes an "open door" to malicious attacks. This possible vulnerabilities need to be checked and security measures needs to evolve at the same speed of IoT growth.

- **Privacy**: Nowadays, internet already faces many privacy problems. Due to the nature of IoT devices, and its use on almost any situation, many private information is stored on servers and that leads to questions like: "is my privacy assured?", "could companies access my private data?". Voice recognition is being used on devices like Amazon Echo which sends recordings of our voice to cloud servers. This kind of devices can continuously listen to conversations, dealing therefor with very sensitive data. The collection of this information exposes legal and regulatory challenges facing data protection and privacy law that needs to be surpassed.

- **Interoperability**: This is one of the main challenges in the IoT world and also the barrier we want to surpass in this work with the integration of the

different devices. As discussed in this chapter, there are many communication protocols used by devices and different platforms providing the necessary infrastructure to ensure communication between devices. The absence of a unique standard consequently allows each device to use their own implementation and, therefore, IoT interoperability continues to be a big challenge. There has to be an effort inside the main IoT companies to agree on a global standard that defines the rules for every IoT devices, however, in my opinion, most companies have other priorities.

- **Data Treatment**: IoT devices generates more and more quantities of data that need to be processed and analyzed, sometimes in real time. Processing and analyzing these large quantities of data will increase at the same proportion the capacity of data centers. This brings to companies new capacity and analytic challenges that has to be surpassed to guarantee the right preparation to the expected IoT growth.

The Interoperability challenge described above is the main reason to the difficulties we face today on IoT devices integration. If we have a unique standard that defines the identification data that all IoT devices has to comply, the automatic integration of devices will be an easy task. In that case, we will know exactly where to get the essential information about each specific device and easily integrate it in any new environment or platform. However, due to this limitation, we have to find another ways of doing this integration automatically, and that is what we will try to accomplish with the prototype described on next chapter.

Chapter 3

Prototype on Device Discovery

This chapter is divided into three main sections. The first part briefly introduces the purpose and the goals of this prototype. The second part details the architecture used as well as the method approach to obtain the device communication data. The third part presents the application developed to perform the tests and finally, the fourth part, details the algorithms used in device discovery.

3.1 Introduction

With so many devices and their distinct goals, the use of different connection modes is a reality. This diversified way of establishing connections creates a handicap in one of the biggest purposes of the IoT: to make ”Things” connect with each other. In fact nowadays, the user needs to integrate each smart device one by one with their specific procedures. This work plans to bring some help to the user in that particular moment. Each IoT device in our homes connects to the internet through our home network (Permanent Connection).

With the development of a specific software that can listen in our home network, we can receive and see the communication of the devices. You can find an

example in APPENDIX A. Our goal is to analyze this communication and, with some techniques, automatically discover and identify each device that is communicating inside our home network. By identifying each device we can automate or partially automate (depends on the device) the integration process. This prototype will provide an example of this automation technique demonstrating each step of the process discussed on this thesis.

3.1.1 Collaboration with Muzzley

To explaining all the steps of this prototype i need to start explaining the origin of this dissertation. This work was made in collaboration with Muzzley [Muzzley, 2016]. Muzzley is a young start-up company working on the IoT world, and they have the brilliant idea of creating an app that can join together many IoT devices simplifying the way we interact with them. I was surprised with their great working ambient and I feel privileged to be able to do this dissertation with their collaboration. In Muzzley's "home" i can find some IoT devices to work with and thereby to test my prototype. I also benefit of great know-how inside this theme to overcome all my doubts. This work can be very important to Muzzley team because this is a feature that they want to implement in their app in the future and, as a consequence, the main reason for the arise of this dissertation theme.

3.2 Prototype Architecture

To begin our prototype we need to design a structure to define how we will get the data from the IoT devices. As we already know, all the devices sends info into the network that is connected. The first step was to find a way to receive this information so that we can use it on our prototype. Taking advantage of the

huge know-how from Muzzley, i was advised to use a tool called Charles Proxy. This tool is a HTTP proxy that enables a view of all the HTTP and SSL / HTTPS traffic between their machine and the Internet including requests, responses and the HTTP headers and it works as a man-in-the-middle to catch all the info that the devices are sending inside the network. So we will have three main components in this architecture:

- The IoT devices that are sending information through the network (right on figure 3.1)
- A computer that is running Charles Proxy working as man-in-the-middle
- One device (in our case a smartphone) that is receiving information from the devices (left on figure 3.1)

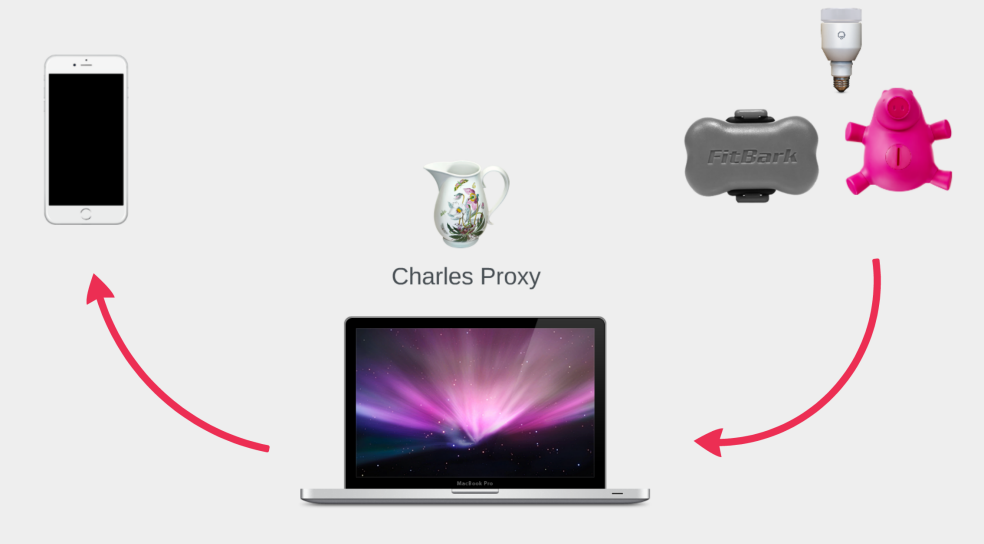

Figure 3.1: Prototype Architecture

When the information is sent from the IoT devices to the destination (in this case the smartphone) the computer acting as man-in-the-middle will be able to see the data. You can find an example of this data in APPENDIX A. This information

will be necessary to prepare our prototype dataset and will also serve as input to test our prototype and try to identify the device that is communicating.

3.2.1 Device Data

Using the method explained above it was possible to get the data to prepare our dataset. Each information we receive from a device is a communication file. One device can generate one or more communication files, for example one smart light can send a file informing the status of color and brightness and other file with the current schedule to turn On/Off. The communication files are sent by the devices in eXtensible Markup Language (XML) or JavaScript Object Notation (JSON) formats. We could not retrieve communication files from all the devices because some of them, even with the Secure Socket Layer (SSL) certificate installed on Charles Proxy, remains encrypted. In our data collection we were able to get info from 15 different devices (Figure 3.2). These devices originated a total of 37 communication files. Afterwards we made another data collection where able to get an additional 24 communication files from 5 new devices.This was the data we use to start out tests.

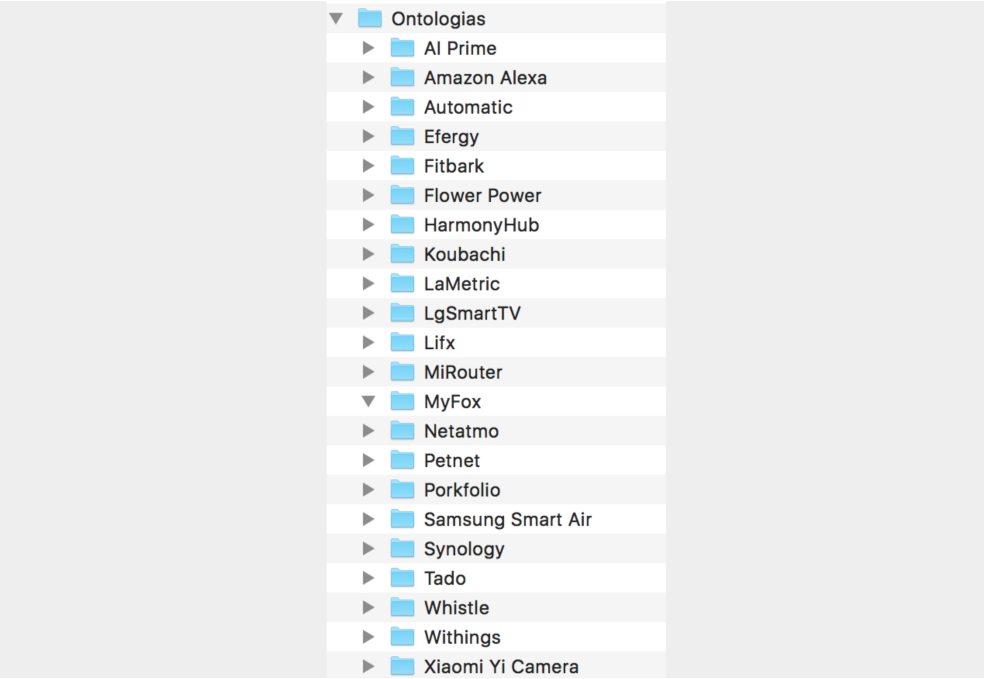

Figure 3.2: IoT Devices List

3.3 App Development

After having in our possession all the communication files from the previous step it was necessary to start developing our prototype so that we can make use of the data already acquired. Taking in account the fact that Muzzley product is a smartphone app and that nowadays we also use our phones to consume IoT, it will certainly be a good decision to develop our prototype in a smartphone platform. So our decision was to implement our prototype in a Iphone Operating System (iOS) device (Figure 3.3). The iOS is an operating systems and it runs exclusively on devices made by Apple company. It is the second most used mobile operating system worldwide and Muzzley application also runs in iOS so it can be easier to integrate this functionality on the future.

The Integrated Development Environment (IDE) used to develop this app was

Xamarin Studio. Xamarin [Xamarin, 2016] is a platform that helps developers to share an average of 75% of app code across all the three main mobile systems. Thanks to this platform, although this app was made to work on iOS, it can easily be modified to be compatible with windows mobile and android.

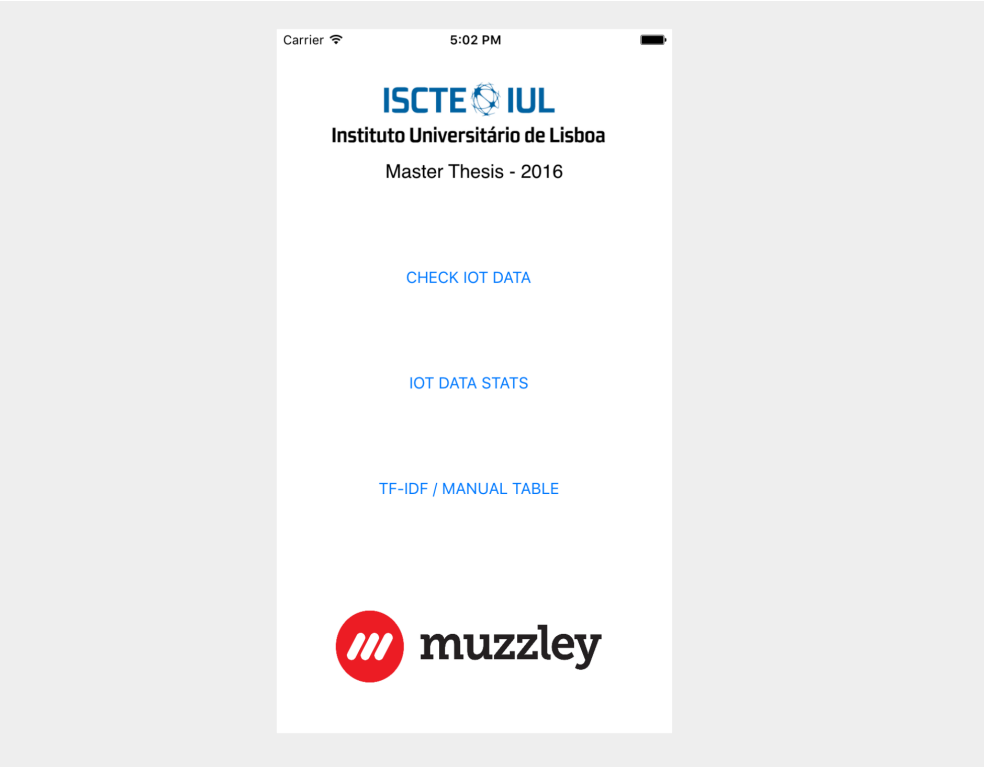

Figure 3.3: App Home Page

The app is prepared to receive the communication files and perform two main tasks:

- Create a database that will store the received communication files, well organized and prepared to be used
- Try to identify a device based on the received communication file by performing the necessary algorithms

The application source code is available at [Bitbucket, 2016].

3.3.1 Import Data

The data import process is a crucial stage inside the app because we need to be sure that we store the information received on the communication files the right way. The objective is to have the information prepared to be used by the algorithms on the device discovery stage. To accomplish this we separate each property from the respective value. One communication file have many properties. In Figure 3.4 we can see the property (”ActivityValue”) and the respective value (”30029”). We pick each of this values and distinguish them inside the database. We also add as a parameter the value type of the property, it can be a single value property or a multiple value property

Figure 3.4: Property and Value Example

At the moment of importation of the communication file we specify the category and the name of the device (Figure 3.5). The categories are predefined on total of 9 categories: ”Security”, ”Other”, ”Health”, ”Activity”, ”Sensor”, ”Con-

troller", "Light", "Display", "Utility". This will enrich the information of each property. Finally we also store the name of the communication file as parameter.

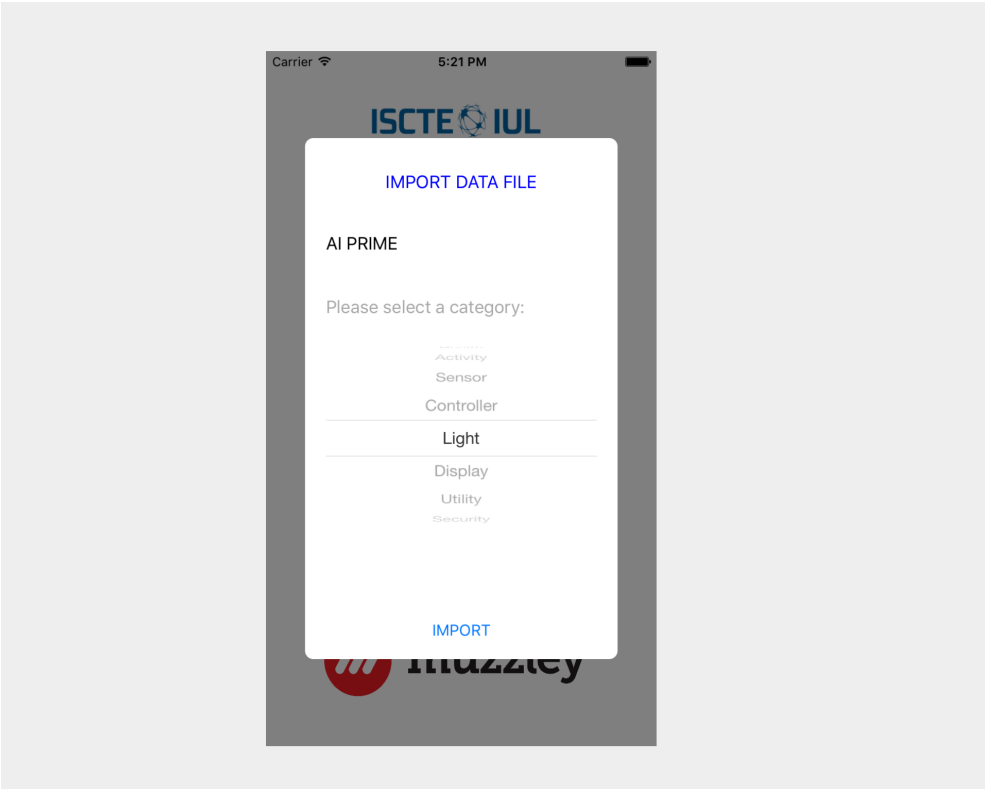

Figure 3.5: Import Menu

So, to summarize, for each line of the database table we store the following "parameters":

- Property
- Value
- Device
- Type (Category)
- Value Type
- Parent File

After importing all the 37 communication files we were able to retrieve a total of 17547 proprieties into the database table. Figure 3.6 illustrates a view of this table inside the app.

PROPERTY VALUE	DEVICE (TYPE) VALUE TYPE
brightness 1	LIFX (Light) Single
color hue,saturation,kelvin,	LIFX (Light) Multiple
hue 0	LIFX (Light) Single
saturation 0	LIFX (Light) Single
kelvin 9000	LIFX (Light) Single
power off	LIFX (Light) Single
group luid,name,updated_at,	LIFX (Light) Multiple
luid 5329adf26e30d9c6050f49cebd70f9d0	LIFX (Light) Single
name Sala	LIFX (Light) Single
updated_at 1438103547	LIFX (Light) Single
location luid,name,updated_at,	LIFX (Light) Multiple
luid 3b1dfb0dda23a508ec6e118c6c29fa82	LIFX (Light) Single

Figure 3.6: Properties Table

3.3.2 Device Discovery

The other stage of the process is actually our main goal: identify the device. The iOS app is prepared to receive both XML or JSON formats and when it receives a new communication file, besides the possibility to add it to database we can also select the option ”Discover Device”. This option has the purpose of use the database and the received properties on the communication file input to try to

identify the device or the category of the device. This identification can be made with different algorithms that we will detail below.

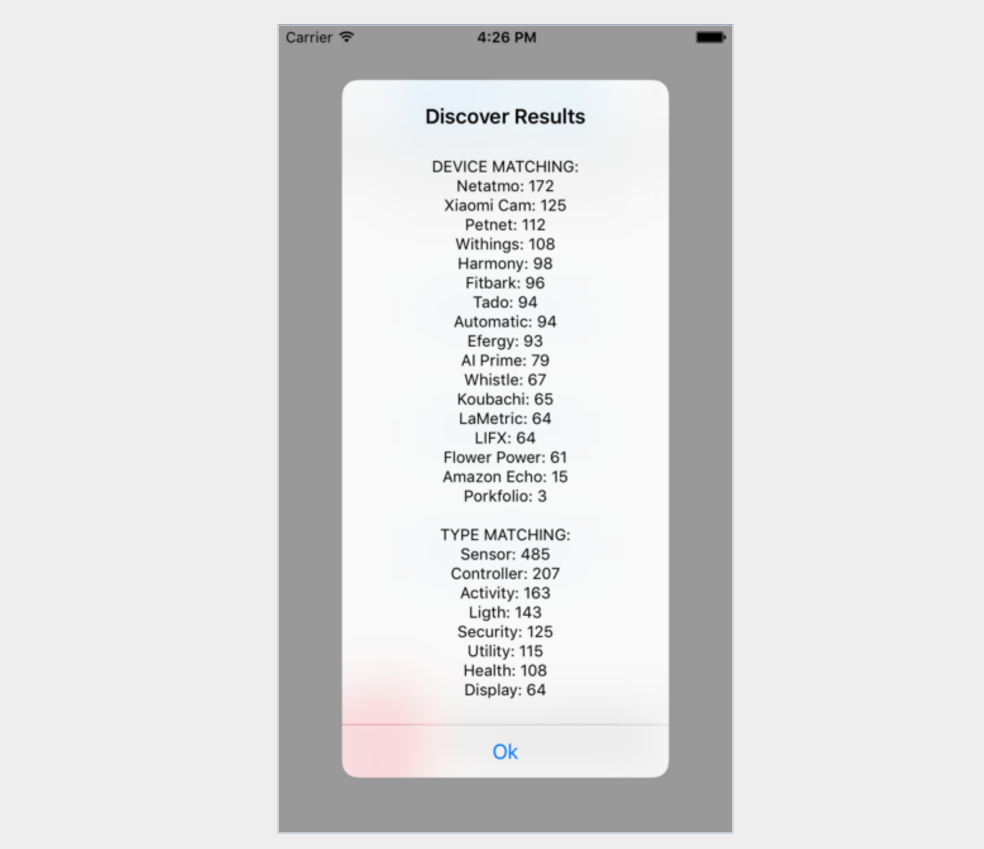

Figure 3.7: App Discover Mode

3.4 Testing Device Discovery

Now that we have all the elements to test the device discovery we need to find strategies to relate the info present on the database with the info received from the device that we wish to identify. During our work we select three different approaches: The ”Levenshtein Algorithm”, making use of a Manual Keyword Table, and finally the TF-IDF table approach. As we can see on Figure 3.8, when

we receive the new communication file in the app we are able to select one of those to start the discovery process.

Figure 3.8: Discover Test Options

After selecting the desired option, the user just need to click on ”Start Discover” and one of the detailed algorithms below will start running on the app.

3.4.1 Manual Table

The most basic approach we take to find the most relevant properties in each category is a Manual Entry table. We can add new entries by placing a property name and define a value from 0 to 1 that corresponds to the relevance of the property. An example of how this entry is added to the table is showed in Figure 3.9. In this case, ”Kelvin” is a very relevant property in ”Light” category and the

presence of this property in a communication file is a important factor to conclude that is a ”Light” type device.

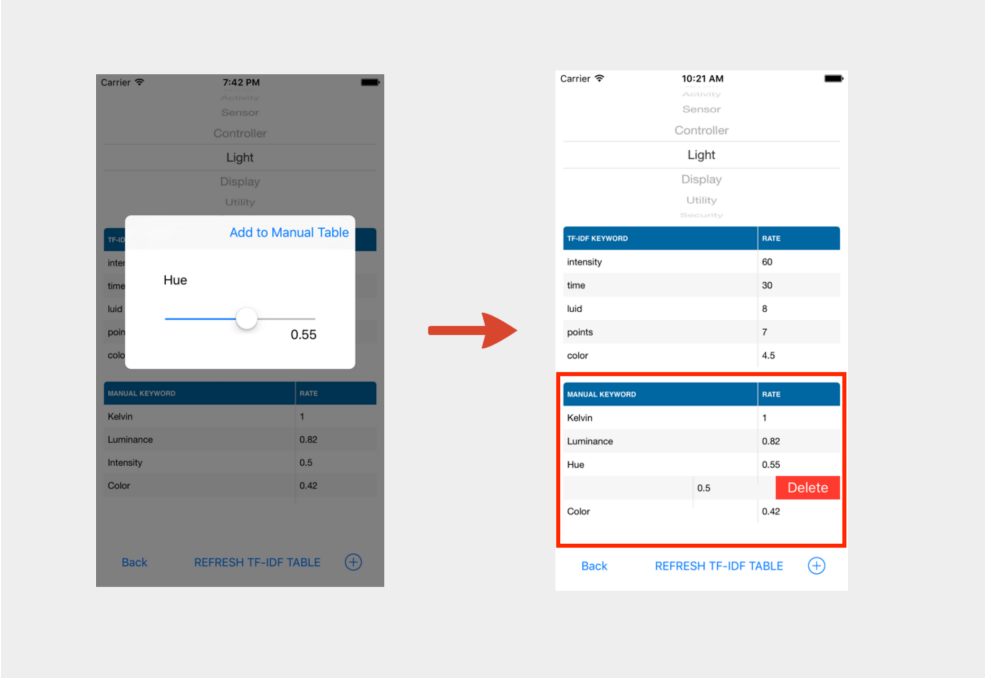

Figure 3.9: Manual Entry Table

3.4.2 TF-IDF Table

Besides the manual keyword table, we also use a special table that is based on a different statistic approach. Using the TF-IDF value we can generate a table where we can find the most significant words inside each category. TF-IDF algorithm value is calculated ”by determining the relative frequency of words in a specific document compared to the inverse proportion of that word over the entire document corpus. Intuitively, this calculation determines how relevant a given word is in a particular document. Words that are common in a single or a small group of documents tend to have higher TF- IDF numbers than common words

such as articles and prepositions"[Ramos, 2003]. The formula is shown in Equation 3.1.

$$W_{x,y} = tf_{x,y} \times log(\frac{N}{df_x}) \tag{3.1}$$

where:

$tf_{x,y}$ = frequency of $_x$ in $_y$

df_x = number of documents containing $_x$

N = total number of documents

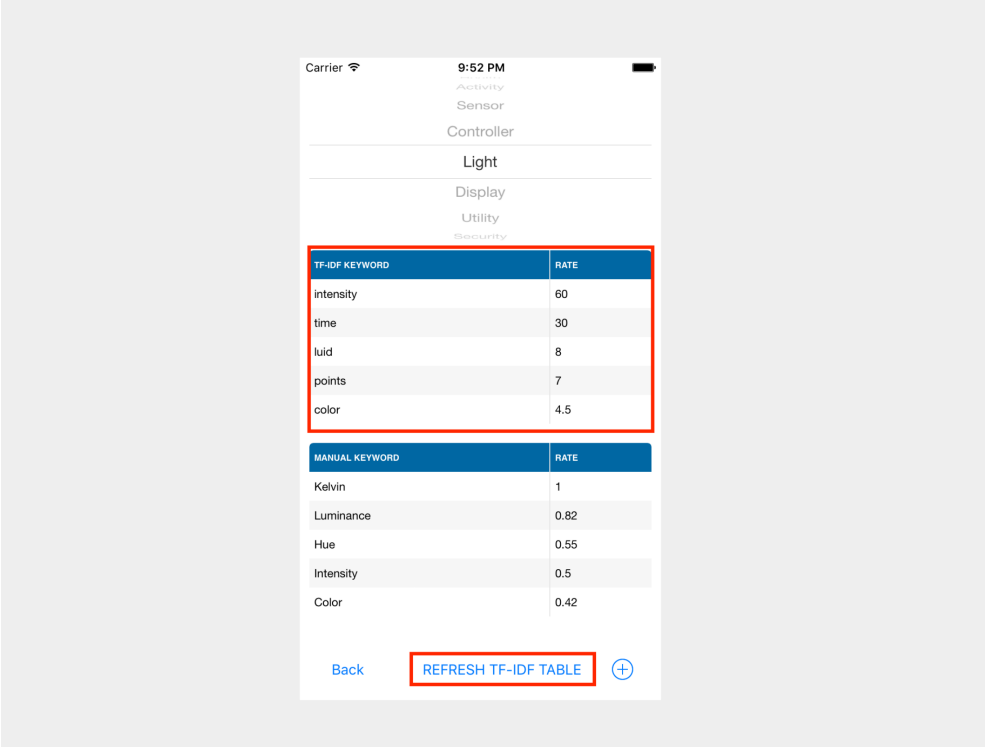

Figure 3.10: TF-IDF Table

To find the most relevant properties in each category, in this prototype, we calculate the frequency of a property in all communication files, comparing it with the frequency of a property in the communication files of a specific category. We

can see an example of the TF-IDF table for the category ”Light” on Figure 3.11. At the end of the algorithm it will appear a list of the devices and categories that contains more total ”value” based on the TF-IDF values calculated in this table.

3.4.3 Levenshtein Algorithm

The Levenshtein Distance Algorithm is a string metric for measuring the difference between two sequences and ”it calculates the minimal costs required to change a string of segments into another by means of insertions, deletions or substitutions”[Beijering et al., 2008]. So, for instance, let’s imagine that we have two proprieties values (strings), one from the new device and one from the database, the Levenshtein Distance value will be the number of modifications needed to transform one string into another. The insertion and deletion of a character in the string have a cost of 1 unit and the substitution of a character has a cost of 2 units.

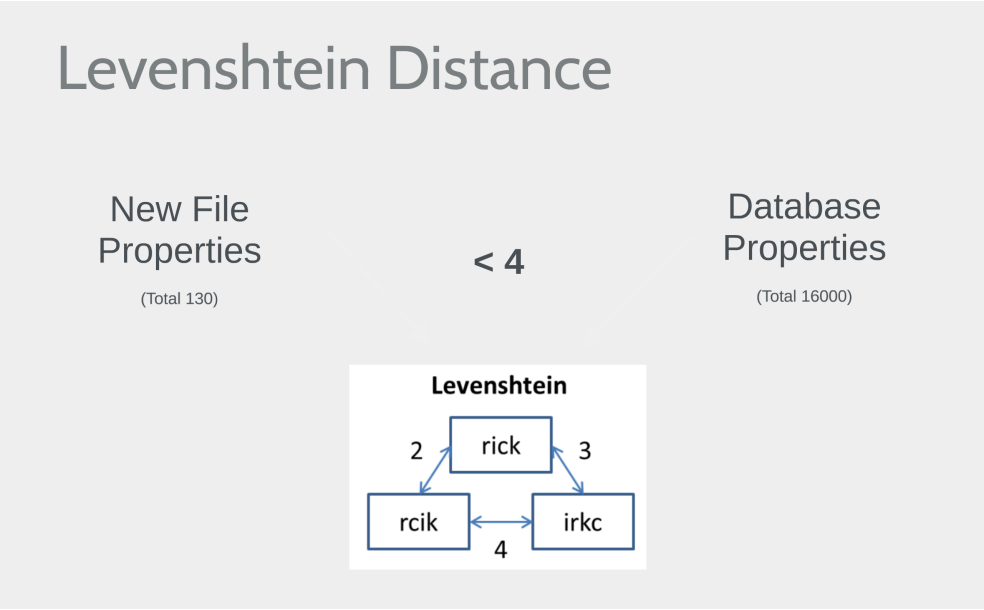

Figure 3.11: Levenshtein Distance Algorithm

In Figure 3.11 we can see that the strings ”rick” and ”rcik” have a Levenshtein Distance value of 2 units because we need to delete the ”c” and insert the ”c” in other position (other solutions with same cost are possible). Due to the relative comparison that we need to accomplish between the information on database and the new device proprieties, this distance value can be applied to our problem. We compare all the proprieties available with the each propriety received in the communication file (from the device that we want to identify).

Now that we have all the values compared, we need to define what is a positive value. After some trial error test we define as a positive match a Levenshtein Distance with value <4 (see Table 4.5 on chapter 4). To exemplify, the word ”color” is a positive match to ”colored”. We also remove the word with less than 4 characters from this comparison like ”ID” or ”key”. At the end of the algorithm it will appear a list of the devices with more positive matches as well as the categories that contains more proprieties that have positive matches.

3.4.4 Synonyms Match

With the aim of getting more positive true matching results we implemented a dictionary of synonyms in our prototype. The main objective is to use each propriety name of communicate file, and, on device discovery, ”transform” it in multiple proprieties with the same meaning. For instance, when the new device have a propriety ”hue” retrieve all the synonyms of this word like ”color” and search for matching proprieties on database for all the synonyms found. This way, if a communication file from a device contains 300 proprieties inside, we can use in our matching algorithm 600 properties or more (including the synonyms). To guarantee this additional information, we needed to find a way to get the synonyms into our prototype. Initially, we started to use a online API [Altervista, 2016].

With this API we can make webservice calls containing a specific word and

receive a list of synonyms. This API is very simple to use, however each call takes about 3 seconds to return values and sometimes the discovery process take 30 minutes or more to complete (depends on the number of properties inside the communication file of the device to discover). We had to choose another approach to retrieve the synonyms of each proprieties. After some research on the internet we were able to find a free English thesaurus file online in [Gutenberg, 2016].

This way we can add this file to our project and parse the synonyms locally almost immediately. This dictionary is very complete with more than 33000 words with synonyms. For example the ”color” word returns the following synonyms: appearance, blackness, exaggeration, falsehood, painting, redness, resentment.

3.4.5 Multi-Property Matching

All the above approaches were property-based, i.e. the attributes used both for training and for testing were those of a single communication of one property per example. This research path was pursued because data, although rich in properties (over 17500), was poor on devices (roughly 20) due to the encrypted communication formats used by many devices (as explained in section subsection 3.2.1) and also because the identification timing is important and the possibility of identifying a device using a single property set action had to be investigated.

Of course, having more information on each device should entail better results, so a final experiment was necessary to assert how the use of accumulated information for one device over a certain time, where several of its properties appear, can affect the results.

We run the TF-IDF algorithm (as explained in section subsection 3.4.2) over the proprieties generated with this method to obtain the most type specific ones (the proprieties that appear frequently on a specific type and not on the remaining). Due to our number of devices used in tests, we have to manually revise these tables

by removing some type unspecific proprieties (i.e. ”status” or ”device”). This last step could be automated with the use of techniques like Principal Component Analysis (PCA) over a database containing a bigger number of devices.

Finally in possesion of these tables we used a technique named K-fold Cross-Validation. This technique consists in dividing data set into k folds (subsamples). Of the k subsamples, a single subsample is retained as the validation data for testing the model, and the remaining k - 1 subsamples are used as training data [Rodriguez et al., 2010]. In this case we divided our data in 10 subsamples of 2 devices. With this 10 subsamples, we use 1 to simulate our new devices and the remaining 9 as our device database. We repeat this process 10 times with different subsamples of new devices.

On each iteration we verify which proprieties of new devices (1 subsample) match with these proprieties. The final output will be a table with the proprieties found and their matches with the devices of each subsample. The advantage of this technique applied in our work is that all the devices in the dataset are eventually used for both training and testing.

Chapter 4

Evaluation

In this chapter we will present the results achieved for each algorithm and evaluate them. We will differentiate two separate test cases:

- Communications from devices that already are in app device database.
- Communications from new devices that are not in app device database.

In first case we are testing new communication files from devices that we already gathered information before. So the communication file is new and may have a completely different set of properties than the last one found, however, he already have proprieties associated with the belonging device inside our database.

In the second case we test new communication files from devices that we never import to the database.

This differentiation is important because the results can differ between a device that we already imported data and a new device which we never gathered information before.

We will also present the results based on two different criteria:

- Based on device.
- Based on type.

On the first we will check which devices returns best results (most ”identical” devices or ideally the same device). On the second we show the matching results by device type.

To evaluate the performance of the algorithms used, the following values are used: the number of correct matches that are correctly classified (true positives (tp)), the number of incorrect matches classified as positive (false positives (fp)), the number of correct matches classified as negative (false negatives (fn)) and the number of incorrect matches classified as negative (true negatives (tn)). From this values it is possible to derive the following performance measures:

Precision (also called positive predictive value) measures the exactness of a classifier, it is the proportion of instances classified as positive that are really positive. If Precision = 1 then fp = 0 means that all positive matches detected are true positives.

$$Precision = \frac{tp}{tp+fp} \tag{4.1}$$

Recall (or sensitivity) measures the completeness of a classifier, it is the proportion of positive instances that are correctly classified as positive. If Recall = 1 then fn = 0 means that all positive matches were detected on the correct class.

$$Recall = \frac{tp}{tp+fn} \tag{4.2}$$

F-measure (or f1-score), is a measure that combines Precision and Recall. The closer to 1 the better.

$$F-measure = \frac{2\times Precision\times Recall}{Precision+Recall} \tag{4.3}$$

4.1 Direct Match

We start the device discovery tests by running a direct comparison of the proprieties from the device to discover and the proprieties we have on our device database.

4.1.1 Devices included on database

First we show the results obtained for devices that we already gathered information before (communication files imported to our test database). On Table D.1 and Table 4.3 we can check the values obtained per device. There was a total of 1689 matching properties from all the devices discovered. The low total number of matching properties occur because we are using an exact match (both names must coincide exactly). The results per device are very good achieving 0.85 of precision and 0.80 on recall value.

Table 4.1: Confusion Matrix for devices included on database by type (Direct Match)

Actual Classes	**Predicted Classes**							
	Lights	**Sensor**	**Activity**	**Controller**	**Display**	**Utility**	**Health**	**Security**
Lights	**114**	24	14	10	8	12	0	8
Sensor	15	**334**	6	1	2	16	9	1
Activity	0	0	**19**	0	0	7	0	0
Controller	0	0	0	**381**	0	0	0	0
Display	5	4	3	2	**10**	6	1	3
Utility	17	23	12	6	7	**227**	6	7
Health	0	13	11	11	0	12	**235**	0
Security	4	4	2	3	4	6	0	**64**

Table 4.2: Classification Report for devices included on database by type (Direct Match)

Classes	**Precision**	**Recall**	**f-measure**	**Support**
Lights	0.74	0.60	0.66	190
Sensor	0.83	0.87	0.85	384
Activity	0.28	0.73	0.41	26
Controller	0.92	1.00	0.96	381
Display	0.32	0.29	0.31	34
Utility	0.79	0.74	0.77	305
Health	0.94	0.83	0.88	282
Security	0.77	0.74	0.75	87
Avg/Total	0.83	0.82	0.82	1689

Table 4.3: Classification Report for devices included on database (Direct Match)

Classes	Precision	Recall	f-measure	Support
Ai prime 1	0.19	1.00	0.32	8
Automatic 2	0.23	0.58	0.33	31
Efergy 3	0.82	1.00	0.90	27
Fitbark 4	0.28	0.73	0.41	26
Flower 5	0.99	0.99	0.99	81
Harmony 6	0.97	1.00	0.98	357
Lametric 7	0.32	0.29	0.31	34
Lifx 8	0.83	0.52	0.64	182
Netatmo 9	0.94	0.80	0.86	245
Petnet 10	0.67	0.56	0.61	163
Porkfolio 11	0.88	0.92	0.90	142
Tado 12	0.53	1.00	0.70	24
Withings 13	0.94	0.83	0.88	282
Yi Cam 14	0.77	0.74	0.75	87
Avg/Total	0.85	0.80	0.81	1689

On Table 4.1 and Table 4.2 we present respectively, the Confusion Matrix and Classification Report for the direct match discovery by device type. In this case we consider as a positive match a propriety that has the same type of the device that is being identified. On these tests the precision slightly reduces to 0.82 (- 0.03) but the recall increase to 0.83 (+ 0.03). These high values are obtained mainly because in both situations, the correct device or type obtains the highest number of matching proprieties.

4.1.2 New devices

After testing devices from database we now tested the discovery on new devices also running a direct comparison. We can see the results of this test on Table 4.4. The values obtained are relatively poor with only 0.39 of precision and 0.24 on recall. There was a total of 903 matching between this new devices and the devices on database. We need make the matching process less restrict to try to obtain more similarities between the properties on new devices and our database. That is what we will try to accomplish with the next tests with the use of other techniques that allows some more flexibility in the matching process like the Levenshtein distance algorithm.

Table 4.4: Classification Report for discovery of new devices by type (Direct Match)

Classes	**Precision**	**Recall**	**f-measure**	**Support**
Light	0.37	0.22	0.28	309
Sensor	0.41	0.21	0.28	360
Activity	0.00	0.00	0.00	0
Controller	0.38	0.32	0.35	234
Display	0.00	0.00	0.00	0
Utility	0.00	0.00	0.00	0
Health	0.00	0.00	0.00	0
Security	0.00	0.00	0.00	0
Avg/Total	0.39	0.24	0.30	903

4.2 Levenshtein Algorithm

In this section we present the results of device discovery running the Levenshtein algorithm against each device. As explained on subsection 3.4.3, after some trial and error tests we found the best results with a Levenshtein distance value of <4 (Table 4.5).

Table 4.5: Classification Report for new devices with different Levenshtein distance

Distance	**Precision**	**Recall**	**f-measure**	**Support**
<**1**	0.39	0.24	0.30	903
<**2**	0.41	0.25	0.31	1004
<**3**	0.44	0.28	0.34	1091
<**4**	0.46	0.31	0.37	1238
<**5**	0.41	0.29	0.33	1584

The number of correct matches increases as the Levenshtein distance rises because it will discover more similar words on the correct properties. However, for distances higher then 3, the incorrect matches starts to grow more quickly than the correct matches and therefore the precision and recall values start a decreasing curve.

4.2.1 Devices included on database

Table E.1 shows the performance of the algorithm acquired for each device. The results are very good and, in all cases, the algorithm was able to match more proprieties with the correct device. Giving as example the device ”Ai Prime”, the new communication file from this device contained 18 matching proprieties from

the other communication files already present our test database. In this case, the second device with more matching proprieties is ”Petnet” and, comparing both, the number is significantly lower (only 3). As an example, the property ”light_on” is a positive match with ”light” for Levenshtein distance <4 but a negative match in case of Direct match (<1).

Table 4.6: Classification Report for devices included on database (Levenshtein)

Classes	**Precision**	**Recall**	**F-measure**	**Support**
Ai prime	0.25	0.56	0.34	32
Automatic	0.12	0.53	0.19	34
Efergy	0.43	0.73	0.55	45
Fitbark	0.41	0.54	0.47	105
Flower	0.99	0.99	0.99	81
Harmony	0.84	0.72	0.78	495
Lametric	0.16	0.22	0.19	45
Lifx	0.69	0.47	0.56	200
Netatmo	0.84	0.65	0.71	314
Petnet	0.42	0.50	0.46	184
Porkfolio	0.74	0.78	0.76	167
Tado	0.47	0.57	0.52	82
Withings	0.84	0.60	0.70	422
Yi Cam	0.52	0.53	0.53	135
Avg/Total	0.70	0.63	0.65	2341

As we saw previously, the discovery obtains more matching proprieties on the correct device in all test cases. Table 4.6 presents some statistical classification for the algorithm performance. The average precision value was 0.70 and the recall 0.63 giving a f-score of 0.65. Despite the relative good results, I think the most important information we acquire here is the fact of, in exception of two

devices, we obtain more true positives than false positives (recall above 0.50 for each device). Another important note is that the positives in the correct device are always superior comparing to any other positives in each single device discovery. There was also a substantial increase on the total matching properties to 2341 comparing with the direct match test.

Table 4.7: Confusion Matrix for devices included on database by type (Levenshtein)

Actual Classes	**Predicted Classes**							
	Lights	**Sensor**	**Activity**	**Controller**	**Display**	**Utility**	**Health**	**Security**
Lights	**128**	30	14	23	11	17	1	8
Sensor	17	**376**	6	18	3	22	11	21
Activity	6	10	**57**	8	4	12	5	3
Controller	27	25	12	**426**	11	33	20	23
Display	6	7	4	6	**10**	7	1	4
Utility	20	48	14	17	8	**227**	10	7
Health	0	45	31	11	10	72	**253**	0
Security	6	29	2	14	6	6	0	**72**

Table 4.8: Classification Report for devices included on database by type (Levenshtein)

Classes	**Precision**	**Recall**	**f-measure**	**Support**
Lights	0.61	0.55	0.58	232
Sensor	0.66	0.79	0.72	474
Activity	0.41	0.54	0.47	105
Controller	0.81	0.74	0.77	577
Display	0.16	0.22	0.19	45
Utility	0.57	0.65	0.61	351
Health	0.84	0.60	0.70	422
Security	0.52	0.53	0.53	135
Avg/Total	0.68	0.66	0.67	2341

On Table 4.7 and Table 4.8 we present the results of the discovery performance using the device type instead of the specific device. Once again we can verify more positives results on the correct type. The precision reduced slightly to 0.68 (-0.02) but the recall value rise to 0.66 (+0.03) leading to a better f-measure value of 0.67 (+0.02). In exception of the type ”Display” all the recall values are above 0.5. We notice that the worst recall results (”Display”, ”Activity” and ”Security”) appear on types that only contained on device of it’s kind in database, this can indicate that, with more devices on test database, the results on type discovery could be better.

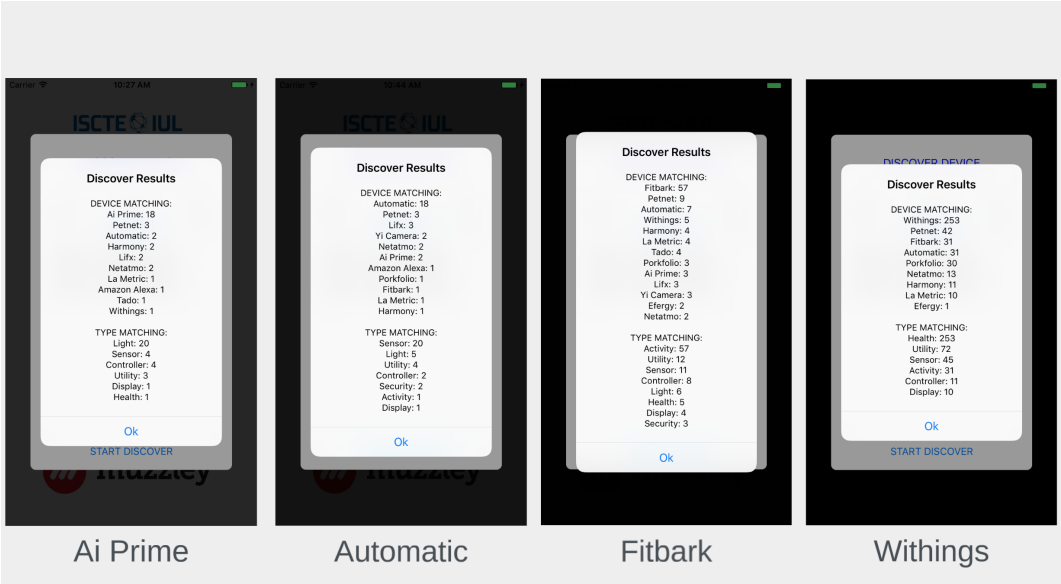

Figure 4.1: Levenshtein Results for devices on database

4.2.2 New devices

Until now, we tested the discovery with devices that we know and already gathered communication files from them. However, when a new device is released to the market we don't have any information about it and we never gathered communication files to our devices database before. To simulate this situation we tested the algorithm performance with 5 new devices. On Table F.1 we can see the matching results for each one of the 5 new devices against the devices we already have on database. Ideally the matching properties should be the more "equivalent" devices (of the same type). A positive match for the new device "Philips Hue" (Light type) should be "Ai Prime" or "Lifx" that are also Light type devices. In our tests, all the new devices except one, have more matching properties on a device of the same type. The exception device was "Nest" that is a controller and have more properties matching (59) with "Netatmo" that is a sensor device. In this case, the second device with more matching properties (55) is the controller type "Tado"

that is the most ”equivalent” device to ”Nest”. Notice that ”Nest”, although it is definitely a controller type, has also a sensor to measure the ambient temperature that is main function of ”Netatmo”.

On Table 4.9 we present the Confusion Matrix for this discovery by type. Here we can see the matching proprieties by type and verify that the most matching properties are contained in the correct type.

Table 4.9: Confusion Matrix for new devices by type (Levenshtein)

Actual Classes	**Predicted Classes**							
	Light	**Sensor**	**Activity**	**Controller**	**Display**	**Utility**	**Health**	**Security**
Light	**105**	62	53	75	30	48	16	31
Sensor	98	**129**	38	60	4	63	51	5
Activity	0	0	0	0	0	0	0	0
Controller	49	94	8	**155**	0	56	7	1
Display	0	0	0	0	0	0	0	0
Utility	0	0	0	0	0	0	0	0
Health	0	0	0	0	0	0	0	0
Security	0	0	0	0	0	0	0	0

Classification report for the same tests are presented on Table 4.10. All the values dropped considerably comparing with the values the discovery of devices on database. However, in my opinion, it’s a good sign to verify that the discovery successfully matched with the correct type. This is the main purpose here because we cant discover what is the specific device (only the most ”equivalent”), but we can identify the specific type of the new device.

Table 4.10: Classification Report for new devices by type (Levenshtein)

Classes	Precision	Recall	f-measure	Support
Light	0.42	0.25	0.31	420
Sensor	0.45	0.29	0.35	448
Activity	0.00	0.00	0.00	0
Controller	0.53	0.42	0.47	370
Display	0.00	0.00	0.00	0
Utility	0.00	0.00	0.00	0
Health	0.00	0.00	0.00	0
Security	0.00	0.00	0.00	0
Avg/Total	0.46	0.31	0.37	1238

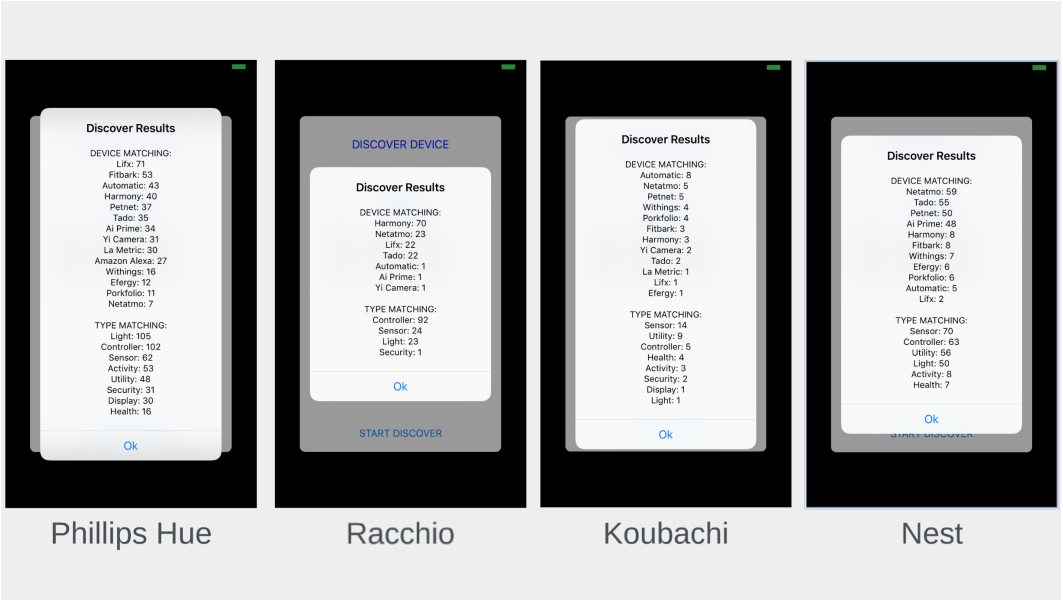

Figure 4.2: Levenshtein Results for New Devices

4.3 TF-IDF Table

We will now present the results of the application of Tf-Idf table in device discovery. As explained on subsection 3.4.2, first we need to generate the Tf-idf tables for each type. As intermediate result we will have one table for each type. Each table have a list of keywords and their respective value calculated with Tf-Idf algorithm, for simplicity we also add a column with the value discretized to 0, 1. We can see on Table 4.11 the top 5 output keywords for the algorithm applied to type ”Light”. The keywords ”intensity” and ”color” are very good results and can help improving the discovery precision, however ”time”, ”luid” and ”points” are generic words and not specific to ”Light” type. The word ”intensity” receive an higher value because the keyword ”intensity” don’t exist in any document of other device type. In this case, if the discovery algorithm find a match with ”intensity”, it will increment 0.28 points on type ”Light”.

After all the tables are generated with the respective discretized values calculated, we can now match the properties of the device to discover. Since our keyword tables are based on device type, the results are only based on type and not on specific device. On Table 4.12 and Table 4.13 we summarize the results obtained from devices of our database and new devices (respectively).

Table 4.11: TF-IDF Keywork table for type ”Light”

Keyword	**Rate**	**Discretized Value**
intensity	60	0.281
time	30	0.141
luid	8	0.037
points	7	0.033
color	4.5	0.021

Table 4.12: Classification Report for Devices on Database (TF-IDF)

	Precision	**Recall**	**f-measure**
Average Result	0.70	0.67	0.66

Table 4.13: Classification Report for new devices (TF-IDF)

	Precision	**Recall**	**f-measure**
Average Result	0.42	0.32	0.32

The discovery of devices in our database reach 0.70 for precision and 0.67 for recall. Although lower than the obtained on Levenshtein algorithm, the results were satisfactory. The same can not be said for the new devices discovery results, with a precision of 0.42 and recall 0.32. The main reason of this lower values is the fact that some keywords more generic (not specific to a type like ”name”) should have lower values. With a bigger database, this kind of words will have more chances to appear on communication files from other device types, and thereby achieve a lower value.

4.4 Synonyms Match

In this section we present the results of device discovery using a dictionary of synonyms. As explained on subsection 3.4.4, we try to improve our results introducing synonyms on the matching algorithm. This way, we will try to match not only each property but also all the synonyms related to each property. On Table 4.14 we present the results for the devices on database. As expected, the Support number increases and we were able to match more 170 proprieties (synonyms) in this test comparing with the results in subsection 3.4.3. Unfortunately this new matching values not only found the same type devices but also other

ones (not the correct device). This leads to a drop on precision and recall values to 0.66 and 0.64 respectively (difference of - 0.02 in both cases comparing with Levenshtein Algorithm).

Table 4.14: Classification Report for Devices on Database by type (Synonyms)

Classes	**Precision**	**Recall**	**F-measure**	**Support**
Avg/Total	0.66	0.64	0.64	2511

Regarding the tests for new devices, we can say that the results were better. As we can see on Table 4.15, similarly to the devices on database, the support value also raised to 1287 (more 49 matched proprieties). However, the matched synonyms words were more assertive on the correct devices types providing an increase of 0.02 on precision and recall comparing to Levenshtein tests.

Table 4.15: Classification Report for new devices by type (Synonyms)

Classes	**Precision**	**Recall**	**F-measure**	**Support**
Light	0.46	0.29	0.35	441
Sensor	0.47	0.30	0.36	476
Activity	0.00	0.00	0.00	0
Controller	0.52	0.42	0.46	370
Display	0.00	0.00	0.00	0
Utility	0.00	0.00	0.00	0
Health	0.00	0.00	0.00	0
Security	0.00	0.00	0.00	0
Avg/Total	0.48	0.33	0.39	1287

4.5 Multi-Property Matching

Our last tests was made using the Multi-Property matching technique. As detailed on Table 4.16, with this method we get the advantage of use the most specific proprieties of each device type and the possibility of use all devices for both training (device database) and testing (new device discovery). In Appendix G we can find a table with all the results obtained for each propriety. The result for each propriety/device test can be ”1” in case of a propriety match occurs and ”0” otherwise. On Table 4.16 and Table 4.17 we can find the Classification Report and Confusion Matrix relative the the results presented on Appendix G.

Table 4.16: Classification Report for discovery of new devices (Multi-Property)

Classes	**Precision**	**Recall**	**f1-score**	**Support**
Light	0.93	0.93	0.93	15
Sensor	0.91	0.91	0.91	22
Controller	0.90	0.86	0.88	21
Utility	0.88	1.00	0.93	7
Activity	0.92	0.80	0.86	15
Display	0.88	0.88	0.88	8
Health	0.78	1.00	0.88	7
Security	1.00	1.00	1.00	7
Avg/Total	0.91	0.90	0.90	102

With the Multi-Property matching method we reach the best result of all the methods tested in this work. The test obtained an average precision of 0.91 and 0.90 of recall. Besides the 10 iterations made possible by this technique, the main factor for this result was the selection of the most specific proprieties for each device/type. Thanks to this detail, it was possible to reach a smaller number of False Positives and thus, achieve higher values.

Table 4.17: Confusion Matrix for discovery of new devices (Multi-Property)

Classes	**Light**	**Sensor**	**Controller**	**Utility**	**Activity**	**Display**	**Health**	**Security**
Light	**14**	0	0	0	0	1	0	0
Sensor	0	**20**	2	0	0	0	0	0
Controller	1	2	**18**	0	0	0	0	0
Utility	0	0	0	**7**	0	0	0	0
Activity	0	0	0	1	**12**	0	2	0
Display	0	0	0	0	1	**7**	0	0
Health	0	0	0	0	0	0	**7**	0
Security	0	0	0	0	0	0	0	**7**

Chapter 5

Conclusion

5.1 Final Remarks

In 2020, 5 billion devices are expected to be in operation worldwide. Due to it's exponential growth, IoT is facing many challenges. One of these challenges is the decentralization of the existent implementations and platforms. Each company uses their own way to integrate the devices and there is no standard. So there are a mass of separated technologies and devices, but there are few integrated services. Therefore, a holistic design implementation is demanded to effectively integrate the scattered devices and technologies into more valuable services. This work attempted to provide an holistic view on the devices discovery and automatic integration phases reducing the existent decentralization effect. This automatic integration process relies on an effective way to identify the device that is exchanging communication data.

We try to prove the possibility to identify an IoT device type using the communication data exchanged between them. In chapter 3 we detailed the method used to prove this possibility. In a first step we gathered the necessary communication data by listening to network traffic containing some of these devices and using a method named man-in-the-middle. This data was then used to generate a de-

vice information database that stores the proprieties of each device. Finally, using this database, we tried to correctly identify devices that are communicating inside a network, testing some techniques like the Levenshtein Distance algorithm, TF-IDF tables, Synonyms Match and finally Multi-Property matching. We differentiate the tests made for devices with some info already imported to our database from the completely new devices with no information gathered yet.

To make these tests we also developed a mobile application as a prototype. This prototype is capable to generate and manage a device information database by importing the communication files originated by IoT devices. This application is also capable of run the algorithms discussed in this work and to return the results for each one.

On chapter 4 we presented the result for each of the tests. We started to test the device discovery by using the Direct Match. This method returns great results for devices on database but poor results for new devices. Then we tested the Levenshtein Distance algorithm and, besides lower results on devices on database, we achieved better results on new devices tests. Trying to improve this result we also tested the use of TF-IDF tables and synonyms match but with few to none improvements on both.

All the above tests are property-based methods. It was chosen this approach due to the nature of our data, rich in properties but poor on devices (roughly 20) due to the encrypted communication formats used by many devices. Of course, having more information on each device should entail better results, so we run a multi-property matching technique over a database generated with the TF-IDF algorithm containing specific proprieties by type. This final results were very good (precision of 0.91) and we can verify that, with correctly valued TF-IDF tables (type specific proprieties), it is possible to identify the device type with good precision.

With the growing number of IoT devices on the market, an efficient integration is becoming more and more important. We think this results are promising and

demonstrate that the use of communication data from these devices can be used to reach this objective.

5.2 Future Work

With the devices used in our work we were able to gather a total of 17547 properties. Although a considerable number of properties, it would be interesting to run these tests over bigger databases to get better results, namely on generation of the TF-IDF tables.

On the device data import phase we were unable to get information from some devices. The information was received encrypted even with the SSL certificate installed on the man-in-the-middle machine. Until the finish date of this thesis, we were unable to discover the reason and it will be important as future work to overcome this barrier.

Regarding our mobile application prototype, it can be improved in some areas. The design can be improved to be easier to receive the communication data files. The import data phase can be enhanced by developing a method to receive many files all at once (currently it can only receive one at a time). Finally a method should be developed to make a search over the properties database.

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Appendix A

Original Scheduling Plan

Task	Description	Deadline
Problem Definition and State of the Art	- Problem definition discussion with Professor Luis Nunes - Research of bibliography regarding actual State of the Art - Development of the State of the Art on the existing IoT systems, protocols and Connection Modes - January presentation of the State of the Art	7 weeks 15-01-2016
Solution Design and Requirement Analysis	- Obtaining ontologies from sniffing through the Man-in-the-middle method. - Analyze the requirements for the implementation of device integration system. - Solution Design.	4 weeks 15-02-2016
Solution Implementation	- Develop an automatic device integration system IoT based on signals generated by devices when connected to an home network.	15 weeks 15-05-2016
Solution Tests and Evaluation	- Analyze the performance and effectiveness of the integrated system.	3 weeks 30-06-2016
Writing Thesis	- Progression on the thesis writing throughout all the planning phases.	10 weeks 31-08-2016

Table A.1: Original Scheduling Plan

Appendix B

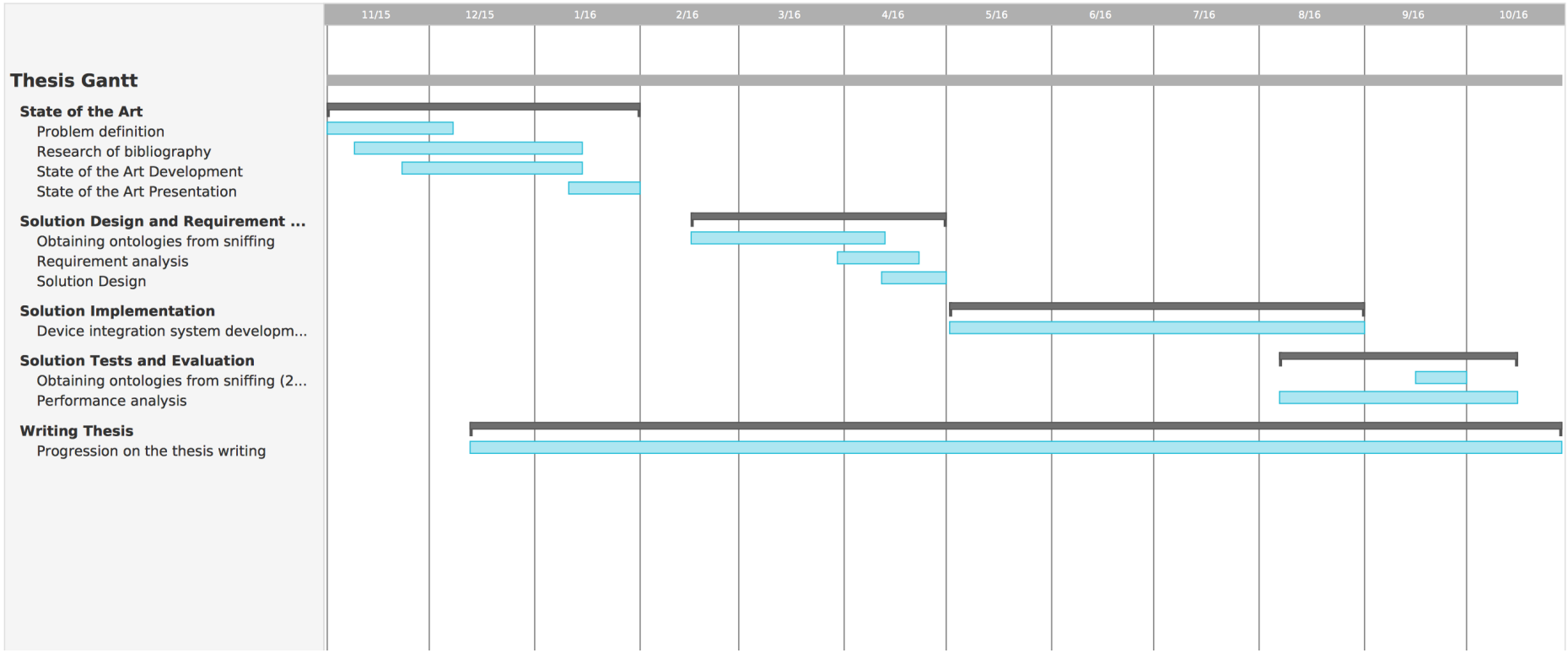
Real Scheduling Plan

Task	Description	Conclusion Date
Problem Definition and State of the Art	- Problem definition discussion with Professor Luis Nunes - Research of bibliography regarding actual State of the Art - Development of the State of the Art on the existing IoT systems, protocols and Connection Modes - January presentation of the State of the Art	7 weeks 15-01-2016
Solution Design and Requirement Analysis	- Obtaining ontologies from sniffing through the Man-in-the-middle method. - Analyze the requirements for the implementation of device integration system. - Solution Design.	10 weeks 30-04-2016
Solution Implementation	- Develop an automatic device integration system IoT based on signals generated by devices when connected to an home network.	20 weeks 31-08-2016
Solution Tests and Evaluation	- Validate the possibility of adapting the solution to an existing IoT system. - Analyze the performance and effectiveness of the integrated system..	6 weeks 15-10-2016
Writing Thesis	- Progression on the thesis writing throughout all the planning phases.	18 weeks 31-10-2016

Table B.1: Real Scheduling Plan

Appendix C

Thesis Gantt Chart


Thesis Gantt
State of the Art
Problem definition
Research of bibliography
State of the Art Development
State of the Art Presentation
Solution Design and Requirement ...
Obtaining ontologies from sniffing
Requirement analysis
Solution Design
Solution Implementation
Device integration system developm...
Solution Tests and Evaluation
Obtaining ontologies from sniffing (2...
Performance analysis
Writing Thesis
Progression on the thesis writing
11/15
12/15
1/16
2/16
3/16
4/16
5/16
6/16
7/16
8/16
9/16
10/16

Appendix D

Confusion Matrix for devices included on database (Direct Match)

Table D.1: Confusion Matrix for devices included on database (Direct Match)

Actual Classes	Predicted Classes (Device Number)													
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Ai Prime (1)	**8**	0	0	0	0	0	0	0	0	0	0	0	0	0
Automatic (2)	1	**18**	0	1	0	1	1	3	1	3	1	0	0	1
Efergy (3)	0	0	**27**	0	0	0	0	0	0	0	0	0	0	0
Fitbark (4)	0	0	0	**19**	0	0	0	0	0	7	0	0	0	0
Flower P (5)	0	0	0	0	**80**	0	0	0	0	0	1	0	0	0
Harmony (6)	0	0	0	0	0	**357**	0	0	0	0	0	0	0	0
LaMetric (7)	3	3	0	3	0	0	**10**	2	1	4	2	2	1	3
Lifx (8)	12	20	0	14	0	0	8	**94**	4	12	0	10	0	8
Netatmo (9)	6	10	2	5	0	0	1	5	**196**	11	0	0	9	0
Petnet (10)	10	2	3	12	0	0	7	7	7	**92**	4	6	6	7
Porkfolio (11)	0	10	0	0	1	0	0	0	0	0	**131**	0	0	0
Tado (12)	0	0	0	0	0	0	0	0	0	0	0	**24**	0	0
Withings (13)	0	10	1	11	0	11	0	0	2	2	10	0	**235**	0
Yi Cam (14)	2	4	0	2	0	0	4	2	0	6	0	3	0	**64**

Appendix E

Confusion Matrix for devices included on database (Levenshtein)

Table E.1: Confusion Matrix for devices included on database (Levenshtein)

Actual Classes	Predicted Classes (Device Number)													
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Ai Prime (1)	**18**	2	0	0	0	2	1	2	2	3	0	1	1	0
Automatic (2)	2	**18**	0	1	0	1	1	3	2	3	1	0	0	2
Efergy (3)	0	0	**33**	0	0	0	0	0	6	0	0	0	0	6
Fitbark (4)	3	6	2	**57**	0	4	4	3	2	9	3	4	5	3
Flower P (5)	0	0	0	0	**80**	0	0	0	0	0	1	0	0	0
Harmony (6)	8	21	0	8	0	**357**	8	13	0	28	0	16	20	16
LaMetric (7)	3	4	1	4	0	4	**10**	3	2	5	2	2	1	4
Lifx (8)	14	20	0	14	0	10	10	**94**	6	14	0	10	0	8
Netatmo (9)	6	12	21	5	0	9	2	6	**204**	13	4	8	11	13
Petnet (10)	12	2	3	13	0	11	8	8	9	**92**	4	6	9	7
Porkfolio (11)	0	32	1	1	1	0	0	0	0	0	**131**	0	1	0
Tado (12)	3	3	0	4	0	6	3	3	1	3	2	**47**	0	7
Withings (13)	0	31	1	31	0	11	10	0	13	42	30	0	**253**	0
Yi Cam (14)	4	5	14	2	0	9	6	2	10	6	0	5	0	**72**

Appendix F

Confusion Matrix for discovery of new devices (Levenshtein)

Table F.1: Confusion Matrix for discovery of new devices (Levenshtein)

Actual Classes	**Predicted Classes**													
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**
Nest (Controller)	48	5	6	8	0	**8**	0	2	59	50	6	**55**	7	0
Phillips Hue (Light)	**34**	43	12	53	0	40	30	**71**	7	37	11	35	16	31
Rach (Controller)	1	1	0	0	0	**70**	0	22	23	0	0	**22**	0	1
Koubachi (Sensor)	0	**8**	**1**	3	**0**	3	1	1	**5**	5	4	2	4	2
Smappee (Sensor)	18	**33**	**32**	35	**0**	37	3	79	**50**	51	3	18	47	3

Appendix G

Multi-Property Validation Table

Type	Keywords TF-ID	Light			Sensor						Controller				Utility		Activity		Display	Health	Security
		Ai prime	Lifx	Philips Hue	Automatic	Efergy	Flower	Netatmo	Koubachi	Smappee	Harmony	Nest	Racchio	Tado	Petnet	Porkfolio	Fitbark	Whistle	Lametric	Withings	Yi Cam
	Intensity	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	hue	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	color	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	blue	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	saturation	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	kelvin	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	brightness	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	driver	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	distance	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	location	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
	khw	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	temperature	0	0	0	0	0	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0
	humidity	0	0	0	0	0	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0
	mist	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	power	0	0	1	0	1	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
	device	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
	command	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
	remote	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	connected	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
	operation	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
	control	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0
	feeding	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	recipe	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	portion	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	hooper	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	deposit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	balance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	breed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
	activity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
	gender	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0
	dog	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
	weight	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0
	streak	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	rest	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	widget	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	animation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	mainscreen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	indicator	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	display	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	frame	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	notification	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	measure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	body	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	height	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	scale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	fatmethod	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	bmi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	impendance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	camera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	viewtime	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	video	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	record	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	alarm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	motion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	visitors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Appendix H

IoT Activity type device communication

In this appendix we can find an example of information sent by a Activity type device type inside a home network. This particular device is a dog activity tracker (Fitbark) and it is communicating the current status.

```
{
    "user_dashboard": {
        "first_name": "Pedro",
        "id": 161,
        "last_name": "Pego",
        "name": "Pedro Pego",
        "picture_hash": "04fafe58ea30b286be2cbac020037098",
        "relations": [
            {
                "date": "2015-05-25T17:07:28.000Z",
                "dog": {
                    "activity_date": "2015-11-24T20:11:17.000Z",
                    "activity_value": 30029,
                    "analytics": {
                        "median_all_dogs_daily_activity": 37157,
                        "median_same_age_weight_daily_activity": 43188,
                        "median_same_age_weight_range_dogs_daily_rest_minutes": 913,
                        "median_same_breed_daily_activity": 49647,
                        "this_average_daily_activity": 65394.25,
                        "this_average_daily_rest_minutes": 725.84,
                        "this_best_daily_activity": 175121,
                        "this_best_goals_streak": 1,
                        "this_best_week_activity": 662208,
                        "this_current_goals_streak": 0
                    },
                    "battery_level": 10,
                    "birth": "2012-02-23",
                    "bluetooth_id": "efb6dd8fc320",
                    "breed1": {
                        "id": 288,
                        "name": "Jack Russell Terrier"
                    },
                    "breed2": {},
                    "country": "PT",
                    "daily_goal": 52000,
                    "gender": "M",
                    "hourly_average": 2753,
                    "id": 1160,
                    "last_min_activity": 0,
                    "last_min_time": "2015-11-24T20:11:00.000Z",
                    "medical_conditions": "1",
                    "min_active": 503,
                    "min_play": 57,
                    "min_rest": 620,
                    "name": "Ruby",
                    "neutered": false,
                    "picture": "http://web.fitbark.com/dogs/901dd12a-477c-4417-8f53-6144d7ae16bf/image",
                    "picture_hash": "6867cd834592f626277001625cb6c3c0",
                    "points_scale": 10,
                    "slug": "901dd12a-477c-4417-8f53-6144d7ae16bf",
                    "threshold_active": 1,
                    "threshold_play": 165,
                    "tzname": "Europe/Lisbon",
                    "tzoffset": 0,
                    "weight": 16,
                    "weight_unit": "lbs",
                    "zip": ""
                },
                "id": 1349,
                "invited_by": null,
                "status": "OWNER"
            }
        ],
        "slug": "096ad88f-dbda-4a78-9af2-b428d07cc630",
        "username": "pedroruben9@hotmail.com"
    }
}
```

Appendix I

IoT Light type device communication

In this appendix we can find an example of information sent by a Light type device type inside a home network. This particular device is a home RGB bulb (LIFX) and it is communicating the current status.

```
{
    "lights": {
        "4": {
            "state": {
                "on": false,
                "bri": 0,
                "hue": 0,
                "sat": 0,
                "effect": "none",
                "xy": [
                    0.0,
                    0.0
                ],
                "ct": 0,
                "alert": "none",
                "colormode": "hs",
                "reachable": false
            },
            "type": "Extended color light",
            "name": "Hue color lamp 2",
            "modelid": "LCT001",
            "manufacturername": "Philips",
            "uniqueid": "00:17:88:01:00:ff:c6:7c-0b",
            "swversion": "5.23.1.13452"
        },
        "5": {
            "state": {
                "on": false,
                "bri": 254,
                "hue": 14910,
                "sat": 144,
                "effect": "none",
                "xy": [
                    0.4596,
                    0.4105
                ],
                "ct": 369,
                "alert": "none",
                "colormode": "ct",
                "reachable": true
            },
            "type": "Extended color light",
            "name": "Hue color lamp 3",
            "modelid": "LCT001",
            "manufacturername": "Philips",
            "uniqueid": "00:17:88:01:00:d1:b4:37-0b",
            "swversion": "5.23.1.13452"
        }
    }
}
```