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Liquid Android: A Middleware for managing Android Intents in a Distributed Net over Wi.Fi

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Abstract

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Chapter 1

Introduction

1.1 Motivation

Nowadays Android is the most common mobile operating system (OS), and it is now clear which it is not only a tiny operating system, but a full functional OS to be used for general purpose. One of the most peculiar characteristic of the Android OS is which it can be installed in a variety of devices such as *"handled"*, like smart-phones and tablets, *"wearable"*, like smart-watches, but also in other kind of things like standard desktops and laptops, smart-tv and tv boxes, and so on.
The great variety of devices described above can run and benefit all the functions of the Android OS which is acknowledged for its ease of use, and the great abundance of applications, with which users can do almost everything.
However one of the greatest limits of Android is that the system was designed to run on the top of a virtual machine and each application which can be executed starts a Linux process which has its own virtual machine (VM), so an application's code runs in isolation from other apps. This technique is called *"app sandboxing"* and it is used to guarantee an high level of security, because different applications can not read write, or worse steal, data and sensible information from other applications.That is, each app, by default, has access only to the components that it requires to do its work and no more. This creates a very secure environment in which an app cannot access parts of the system for which it is not given permission.
Under this limitations the Android OS provides a mechanism to make communicate the various component of the applications and the operating system itself : the so called *"intents"*. An intent is an abstract description of an operation to be performed,it provides a facility for performing late runtime binding between the code in different applications. Its most significant use is in the launching of activities. However, even do the intents can be created and resolved within the same android running devices, there is not a mechanism that can send and resolve intents from a devices to another one.
In a world where computers are everywhere and can do almost everything and can communicate among them in different but efficient ways, the fact that android devices are not able to easily exchange intents is such a major limitation to

the android users. As we know our world is fast moving to a world of *"ubiquitous computing"* where there is no more a single *"fat calculator"* but a variety of multipurpose and specialized devices. In this world of pervasive computation, Android devices are widespread, cheap and powerful enough to do most of the things that we can imagine and would be great if they can be used together in a smart way. The aim of this thesis work is to study enough the android framework to find a solution to this problem, and create a middleware to extend the Android OS, creating a distributed system in which intents can be generated from one device and resolved by others in a net connected in a LAN. This can help developers build distributed native Android application to exploit the power of any different device running the OS and let the users use their own devices such as they were one single big device.
Each sentence or technology, that may appear not clearly explained here for the reader, is further discussed and clarified in next chapters.

1.2 Outline

The thesis is organized as follows:

In the second chapter the state of art is described: a full overview on current technologies, ideas and issues is provided. The chapter starts presenting the Android operating system with a brief history of versions. Then a deep presentation of Android's framework component is give to the reader, including security model and connectivity functionalities. The chapter continue describing what is a distributed system, listing its main challenges, properties and its working mechanism such as the communication models, and architectural patterns. The final section explains the term *Liquid computing*, presenting some existing technologies which can be useful to understand the problem an then the proposed solution and development.

In the third chapter I have defined the faced problem, its constraints and its boundaries. The chapter starts with a contextualization of the given problem, giving a brief recap of the state of the art.Then are provided some restriction, considering only devices in which the developed system could be installed. The chapter continue with the full description of the problem, the main idea and also a working scheme of the component to be developed. Are then presented problematic scenarios to be studied, including detailed description of what the middleware to be implemented should work in these situations. There is, finally, a list of constraints that the system must meet to be considered a good solution to the given problem.

In the fourth chapter

In the fifth chapter

In the sixth chapter

Chapter 2

State of the Art

2.1 Android OS

As already mentioned in 1.1, the Android operating system is an open source OS developed by Google based on Linux kernel, that can be installed on many different kind of devices.
In this section i want to give to the reader the basic knowledge of the Android framework to understand why and how the operating system works.

2.1.1 Brief History

The Android era officially began on October 22nd, 2008, when the *T-Mobile G1* launched in the United States [12].
At that moment the company of mountain view, Google, felt the need to create a new operating system which was able to be installed on most modern mobile phones of the time. To meet this need the Google engineers created an OS that was based on the Linux kernel, lightweight enough and ease to be used with simple hand gestures by touching the screen of the phone.

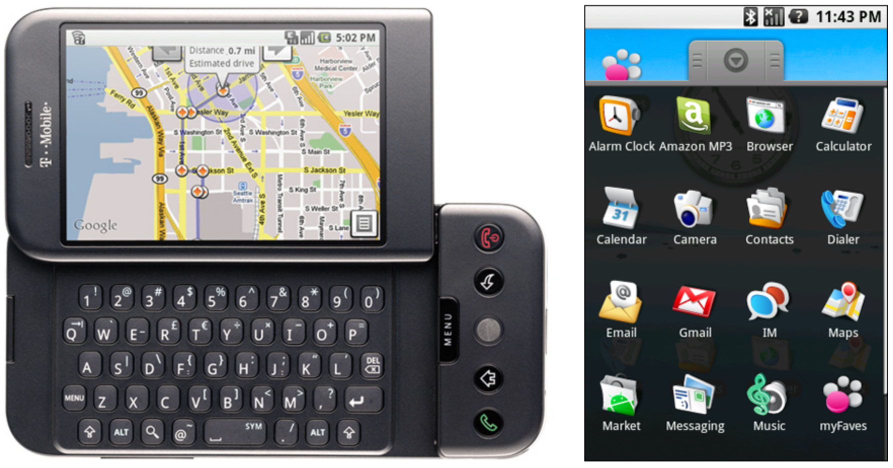


Figure 2.1: The T-Mobile G1 and the Android 1.0 menù

The main characteristic of the OS were and are also now:

- The pull-down notification window.
- Home screen widgets.
- The Android Market.
- Google services integration (eg. Gmail).
- Wireless connection technologies (eg Wi-Fi and Bluetooth)

The success of the first version of the brand new mobile operating system and the open source philosophy guaranteed the fast spread of the Android devices all over the world. In few years Google improved and released many version of the OS and with the help of the market growth Android has become a complete os. In the table below there is a brief description of the various distribution of the Android OS at the time of writing of this document.

As we can see in Table 2.1 there are, currently, 25 level of the Android *API*

Table 2.1: Android versions

Name	**Version**	**Release Date**	**API Level**
Alpha	1.0	September 23, 2008	1
Beta	1.1	February 9, 2009	2
Cupcake	1.5	April 27, 2009	3
Donut	1.6	September 15, 2009	4
Eclair	2.0 – 2.1	October 26, 2009	5–7
Froyo	2.2 – 2.2.3	May 20, 2010	8
Gingerbread	2.3 – 2.3.7	December 6, 2010	9–10
Honeycomb	3.0 – 3.2.6	February 22, 2011	11–13
Ice Cream Sandwich	4.0 – 4.0.4	October 18, 2011	14–15
Jelly Bean	4.1 – 4.3.1	July 9, 2012	16–18
KitKat	4.4 – 4.4.4	October 31, 2013	19
Lollipop	5.0 – 5.1.1	November 12, 2014	21–22
Marshmallow	6.0 – 6.0.1	October 5, 2015	23
Nougat	7.0 – 7.1.1	August 22, 2016	24–25

(Application programming interface) which developers can use to build Android applications. In particular various API levels introduce innovations in the OS but, applications developed using an higher *API level* can not be executed in a device running lower versions of the operating system. This is a second major limitations for the *"Android ecosystem"*, moreover as mentioned before, the Android OS is released under an open source license, which is great for the developer, but which prevents Google to provide updates, in a centralized way, to all devices. For this reason there are currently many active devices running different versions of the mobile OS, as we can check in Table 2.2, which shows, in percentage, the fragmentations of active machines running Android OS.

Data in Table 2.2 were collected during a 7-day period ending on December 5, 2016, by Google. Any versions with less than 0.1% distribution are not shown [7].

Table 2.2: Android OS versions fragmentation

Version	API Level	Distribution
2.2	8	0.1%
2.3.3 - 2.3.7	10	1.2%
4.0.3 - 4.0.4	15	1.2%
4.1.x	16	4.5%
4.2.x	17	6.4%
4.3	18	1.9%
4.4	19	24.0%
5.0	21	10.8%
5.1	22	23.2%
6.0	23	26.3%
7.0	24	0.4%

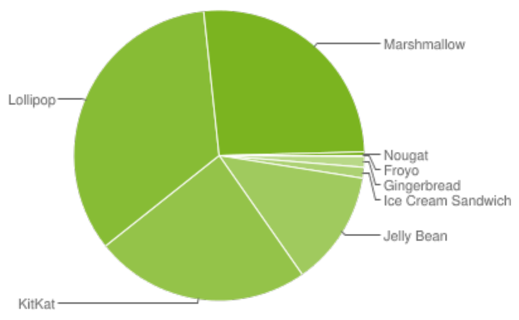


Figure 2.2: Android OS fragmentation chart

2.1.2 Structure

Android is an operating system based on the Linux kernel. The project responsible for developing the Android system is called the *Android Open Source Project (AOSP)* and it lead by Google.

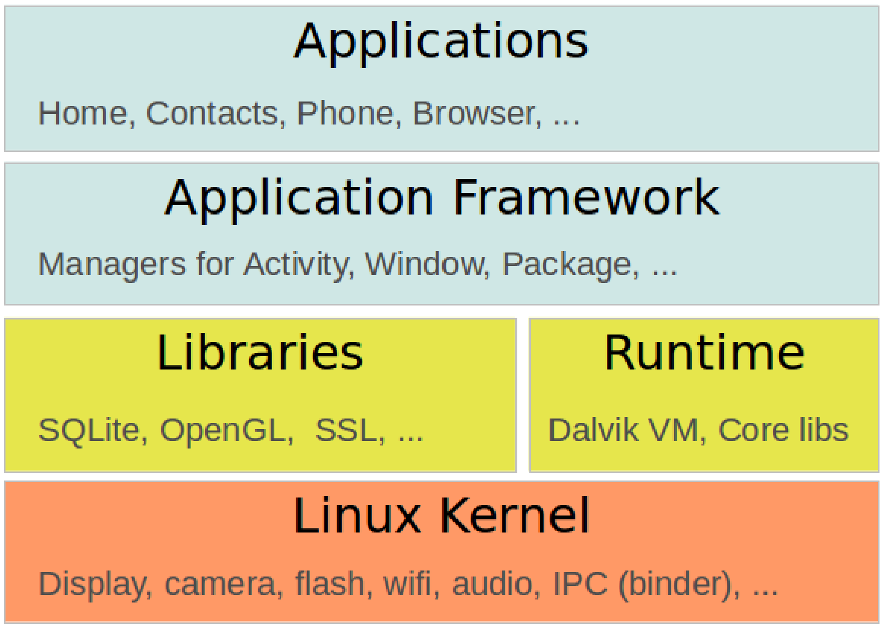

Applications
Home, Contacts, Phone, Browser, ...
Application Framework
Managers for Activity, Window, Package, ...
Libraries
SQLite, OpenGL, SSL, ...
Runtime
Dalvik VM, Core libs
Linux Kernel
Display, camera, flash, wifi, audio, IPC (binder), ...

Figure 2.3: Android OS 4 layers

The OS can be divided into the four layers as depicted the Figure 2.3. An Android application developer typically works with the two layers on top to create new Android applications [14].

Linux Kernel is the most flexible operating system that has ever been created. It can be tuned for a wide range of different systems, running on everything from a radio-controlled model helicopter, to a cell phone, to the majority of the largest supercomputers in the world [10]. This is in practice the communication layer for the underlying hardware.

Runtime and Libraries Runtime is the term used in computer science to designate the software that provides the services necessary for the execution of a program.There are two different *"runtime systems"* which can work with the Android OS:

- *Dalvik VM* is an optimized version for low memory devices of the *Java Virtual Machine (JVM)* used in Android 4.4 and earlier version. It is stack based and it works by converting using a *just-in-time (JIT)*, each time an application is executed, Android's *bytecode* into machine code.
- *ART (Android Runtime)* introduced with Android 4.4 KitKat. This runtime uses an *AOT (Ahead-of-Time)* approach, with which code is compiled during the installation of an application and then is ready to be executed.

Standard Android libraries are for many common framework functions, like, graphic rendering, data storage, web browsing. [14]. This layer contains also standard *java libraries*.

Application Framework is the layer that contains the Android components for the application such as activities, fragments, services and so on.

Applications are pieces of software written in *java code* running on top the other layers.

2.1.3 Application Framework

In this section I want to give some details of the application composition and work flow to better understand the subsequent sections in which I will describe the given problem and the proposed solution.
As briefly described in 2.1.2 the Android application framework *("AppFramework")* is the core of the Android *development API*. It contains useful and needed components to build native apps.
The main components with which each application is composed are:

Intents are objects that initiate actions from other app components, either within the same program *(explicit intents)* or through another piece of software on the device *(implicit intents)*. Acconrding to the official Google's Android for developer documentation, an Intent is a sort of messaging object which can be used to request an action from another application component (eg. activities). There are three fundamental use cases:

- Starting an activity: we will see that activities represents a single screen in Android applications, intents allow to start activities by describing them and carrying any necessary data.

- Starting a service: I will explain later in deeper details that services are component which performs operations in background. As for the activities, services are initialized through intent and in the same way they describe the service to start and carries any necessary data.

- Delivering a broadcast: broadcast is a message that any app can receive. The system delivers various broadcasts for system events, such as when the system boots up or the device starts charging.

As already mentioned there are mainly two categories of intents:

- explicit intents, used when it is needed to start component within the same application. As the name implies explicit intents call components by using by name (the full *class object* name), for example, it is possible to start a new activity in response to a user action or start a service to download a file in the background.

- implicit intents do not name a specific component, but instead declare a general action to perform, which allows a component from another app to handle it. For example, if you want to show the user a location on a map, you can use an implicit intent to request that another capable app show a specified location on a map [5].

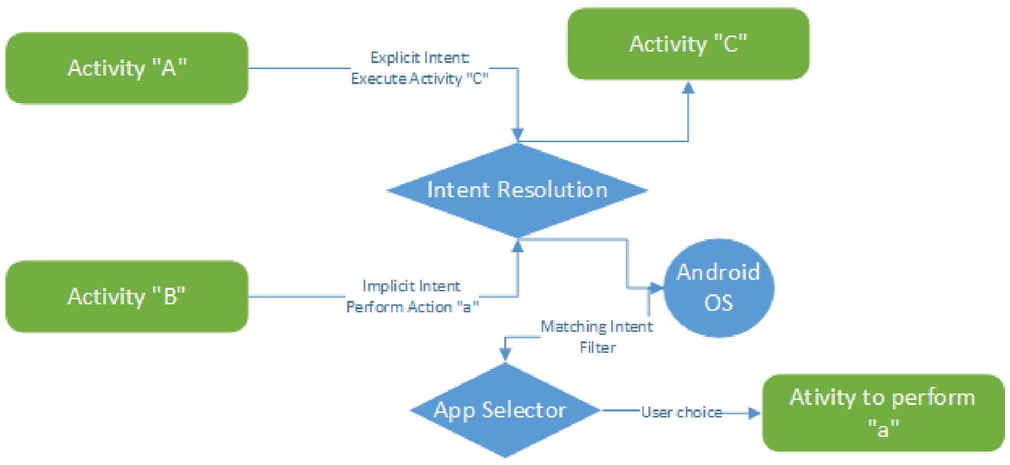


Figure 2.4: Intent resolution mechanism

The Figure 2.4 explains well how an intent is resolved by the OS whether it is implicit or explicit. When an implicit intent needs to be resolved, the OS searches applications which can handle it by means of *intent filters*.A Intent filter specifies the types of intents that an activity, service, or broadcast receiver can respond to. The Android System searches all apps for an intent filter that matches the intent to be resolved. When a match is found, the system starts the matching component, or, if there are more than one, let the user select the preferred action to be performed.

Activities are one of the fundamental building blocks of apps on the Android platform. They serve as the entry point for a user's interaction with an app, and are also central to how a user navigates within an app. [6]. An activity is the entry point for interacting with the user. It represents a single screen with a user interface *GUI*: in this way activities are containers for other Android's GUI elements (eg. buttons, textviews,...).

Services is a general-purpose entry point for keeping an app running in the background for all kinds of reasons. It is a component that runs in the background to perform long-running operations or to perform work for remote processes. A service does not provide a user interface [4].

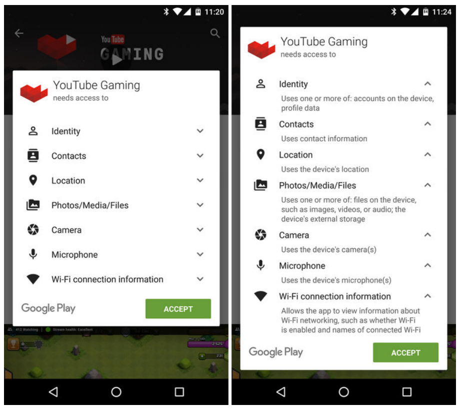
Broadcast Receivers are components that enable the system to deliver events to the app outside of a regular user flow, allowing the app to respond to system-wide broadcast announcements. Because broadcast receivers are another well-defined entry into the app, the system can deliver broadcasts even to applications that aren't currently running [4].

2.1.4 Security

As described in 2.1.1 Android was born to be a good mobile OS and it is mainly for this reason that the system is designed to protect personal and sensible data form malicious guys.
Like the rest of the system, Android's security model also takes advantages of the security features offered by the Linux kernel. Linux is a *multiuser OS* and its kernel can isolate user data from one another: one user can not access another user's file unless explicitly granted permission. Android takes advantages of this user isolation, considering each application a different user provided with a dedicated *UID (User ID)* [8] Android in fact, is designed for smartphones that are personal devices and do not need, usually, a multi physical user support. The most important security techniques adopted by Android are:

Application Sandboxing Android automatically assigns a unique *AppID* (Linux UID) when an application is installed and then executed that specific app in a dedicated process as that UID. This technique isolate all the applications at process level and additionally each app has permissions to read/write a specific and dedicated directory.

Permissions Since application are sandboxed and do not have the rights to read/write date outside them, it is possible to grant additional rights to android applications by explicitly asking them. Those access rights are called *permission*. Applications can request permissions by listing them in a configuration file called *android manifest*. In Android 5.1 and earlier versions permission are inspected and granted at installation time, when the user is alerted with a dialog box in which are listed permissions the application to be installed needs to work properly and when granted cannot be revoked. Starting from android 6.0 permission are asked the first time that an application need them, and when are granted they can be revoked manually in the OS settings for that specific application.


11:20

YouTube Gaming
needs access to

Identity
Contacts
Location
Photos/Media/Files
Camera
Microphone
Wi-Fi connection information

Google Play ACCEPT

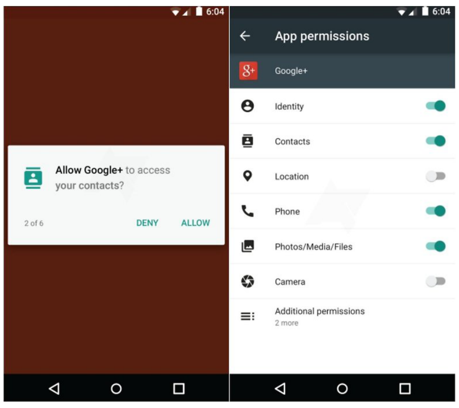
11:24

YouTube Gaming
needs access to

Identity
Uses one or more of: accounts on the device, profile data
Contacts
Uses contact information
Location
Uses the device's location
Photos/Media/Files
Uses one or more of: files on the device, such as images, videos, or audio; the device's external storage
Camera
Uses the device's camera(s)
Microphone
Uses the device's microphone(s)
Wi-Fi connection information
Allows the app to view information about Wi-Fi networking, such as whether Wi-Fi is enabled and names of connected Wi-Fi

Google Play ACCEPT

Figure 2.5: Android 5.1- permission example


6:04

Allow Google+ to access your contacts?

2 of 6 DENY ALLOW

6:04

App permissions
Google+

Identity	●
Contacts	●
Location	○
Phone	●
Photos/Media/Files	●
Camera	○

Additional permissions
2 more

Figure 2.6: Android 6.0+ permission example

Figure 2.7: Android permission Examples

SeLinux Security Enhanced Linux, is a *mandatory access control (MAC)* system for the Linux operating system. With a MAC the operating system constrains the ability of a subject or initiator to access or generally perform some sort of operation on an object or target. Starting in Android 4.3, SELinux provides a mandatory access control (MAC) umbrella over traditional discretionary *access control (DAC)* environments. For instance, software must typically run as the root user account to write to raw block devices. In a traditional DAC-based Linux environment, if the root user becomes compromised that user can write to every raw block device. However, SELinux can be used to label these devices so the process assigned the root privilege can write to only those specified in the associated policy. In this way, the process cannot overwrite data and system settings outside of the specific raw block device [1].

2.1.5 Connectivity

As already amply explained previously many Android design choices are due to the fact that it was thought for mobile devices which must have connectivity to intercommunicate among them.
With the evolution of various wireless communication technologies, Android devices, nowadays, are equipped whit different kinds of modulus, the most common are:

- Wi-Fi
- Bluetooth
- NFC
- Cellular Network

The Android Os provide a full library to operate with these technologies and it is possible to integrate in applications the possibility to communicate over these wireless modules. With the *Android connectivity API* data can be send and received in an efficient way.

I have only quickly listed some features and possible issues of my source, to have a complete idea it is possible to read all the official Android documentation in [4].

2.2 Distributed System

In this section I want to give to the reader some basics about distributed systems, including technical details and examples to make the proposed solution easier to understand.

2.2.1 Definition

A distributed system is a collection of independent computers that appears to its users as a single coherent system.
This definition has several important aspects. The first one is that a distributed system consists of components (i.e., computers) that are autonomous. A second aspect is that users (be they people or programs) think they are dealing with a single system. This means that one way or the other the autonomous components need to collaborate [13].
In Figure 2.8 it is possible to see how can be structured a distributed system: a

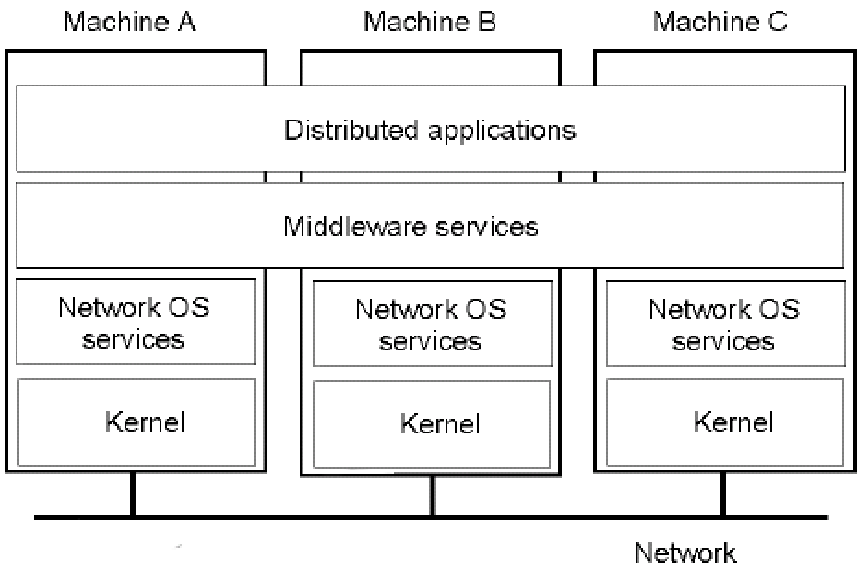


Figure 2.8: Distributed system structure

the top we have the real distributed application, which is the final interface to be used, under which it is possible to have different combinations of services used to make communicate different machines that may use different operating systems. The real magic is done by the layer called *middleware service* in the picture. A middleware in computer science is a set of software which act as intermediaries between structures and computer programs, allowing them to communicate in spite of the diversity of protocols or running OSs.

2.2.2 Challenges

There are many challenges in distributed systems field: distributed applications are often really complex and easily exposed to physical and technical failures because of their nature. Major challenges and property to be considered when developing a system of this kind are:

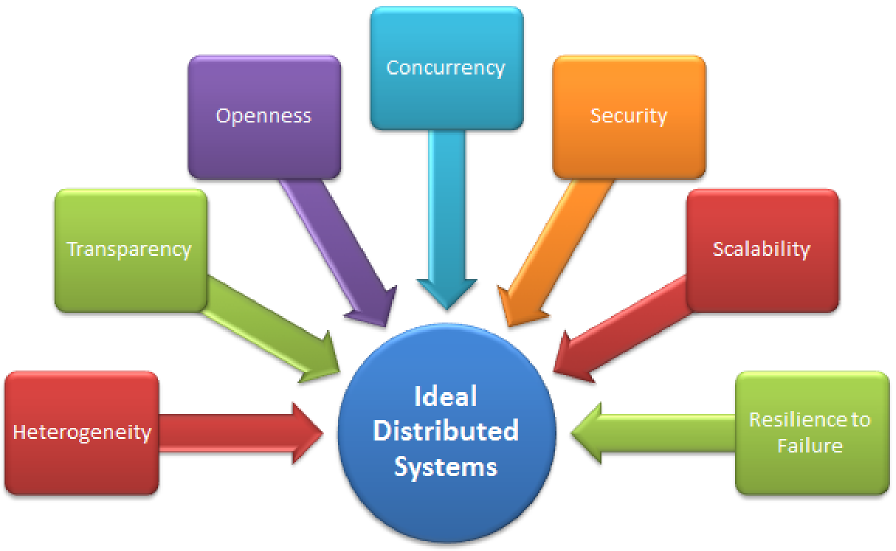


Figure 2.9: Distributed system challenges

- Heterogeneity, is a major challenge because there are many different component to be considered, distributed systems may be developed for example for different hardware, networks, operating systems and programming languages.

- Openness, determines whether a system can be extended and reimplemented in various ways, so distributed systems should use standards as much as possible. Developers should always choose the simplest ways during design and implementation phases.

- Security, is crucial in many areas of computer science and specially in distributed systems, where data are exchanged by a several number of machines.

- Scalability, is the ability to easily increase the size of the system in terms of users/resources and geographic span.

- Failure handling, is important because having different components working together to a common goal means that distributed system can fail in many ways. This raises some issue: it would be nice id distributed systems can detect, mask and tolerate failures.
- Concurrency in distributed systems is a matter of fact, access to shared resources (information or services) must be carefully synchronized.
- Transparency level are listed in Table 2.3

Table 2.3: Transparency levels

Transparency	Description
Access	Hide differences in data representation and how a resource is accessed
Location	Hide where a resource is located
Migration	Hide that a resource may move to another location
Relocation	Hide that a resource may be moved to another location while in use
Replication	Hide that a resource may be shared by several competitive users
Concurrency	Hide that a resource may be shared by several competitive users
Failure	Hide the failure and recovery of a resource
Persistence	Hide whether a (software) resource is in memory or on disk

2.2.3 Comunication Model

There are, in distributed system literature, some well known techniques to let communicate machines, programs and components. Each of the methods described later exploits the network protocols by acting as a middleware: they use and mask lower layer protocols to provide ready to use communication services.

Remote procedure call (RPC) is a paradigm in which a client process invokes a remotely located procedure (a server process), the remote procedure executes and sends the response back to the client [9]. As described in Figure 2.10 RPC provides the localization of the code to be executed exploiting the network transport services, create a message which can be serialized and transferred over a standard network protocol and then provides methods to de-serialize the message and convert in into a standard local procedure call in the receiver machine. Very important in this mechanism is the concept of *ILD* (Interface definition language) which raises the level of abstraction of the service by separating the interface from its implementation: in this way RPC can be language independent by generating automatic translations from IDL to target language.

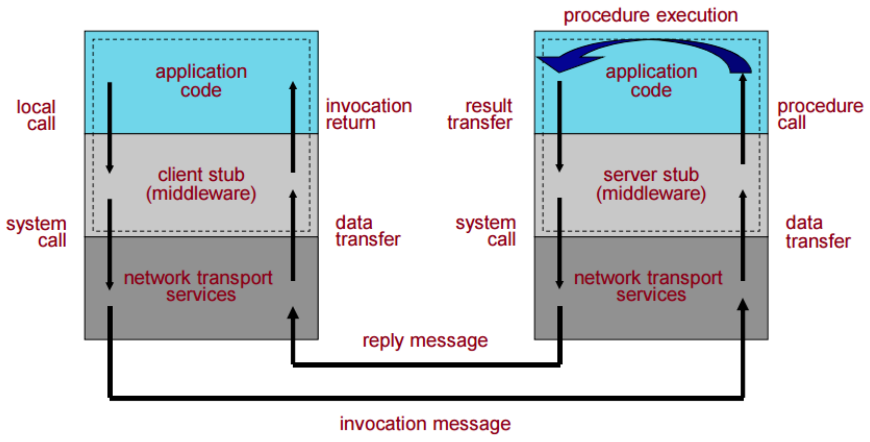


Figure 2.10: RPC in detail

Remote method invocation (RMI) exploits the same idea of RPC but with different programming constructs: it is designed to let communicate object oriented (OO) programming languages. The Figure 2.11 shows in detail how

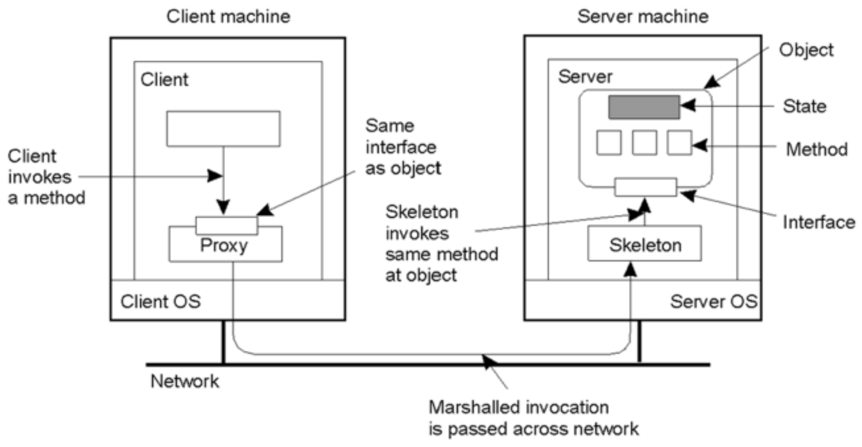


Figure 2.11: RMI in detail

RMI is supposed to work. Like RPC, RMI uses an IDL which is designed to support OO programming languages features such as inheritance and exception handling.

Message oriented communication is a style based and centered on the notion of simple messages and events.The most straightforward example of it is *message passing*. Typically message passing is implemented directly on the network sublayers (eg. sockets). Message passing differs from conventional programming where a process, subroutine, or function is directly invoked by name. In Table 2.4 are shown the most significant differences between RPC/RMI approach and message communication models. Moreover there are some implementation of message passing at middleware layer like *publish-subscribe* which is further explained in the following paragraph.

Table 2.4: Comparison between communication models

RPC/RMI	Message Oriented
• natural programming abstractions • point to point communication • designed for synchronous communication • high coupling between the caller and the callee	• centered around the notion of message/event • multipoint support • usually asynchronous • high level of decoupling

2.2.4 Architectures

There are actually many different kinds of distributed systems which can be classified by means of their architecture composition.

Client-Server is the most common architecture in computer systems, there are many variants depending on the internal division of its components but it has a common separation of duties. Server side components are passive and wait for clients invocations.Client computers provide an interface to allow a computer user to request services of the server and to display the results it returns. Servers wait for requests to arrive from clients and then respond to them. Ideally, a server provides a standardized transparent interface to clients so that clients need not be aware of the specifics of the system (i.e., the hardware and software) that is providing the service. The communication adopted by these kind of systems is message oriented or through RPC.

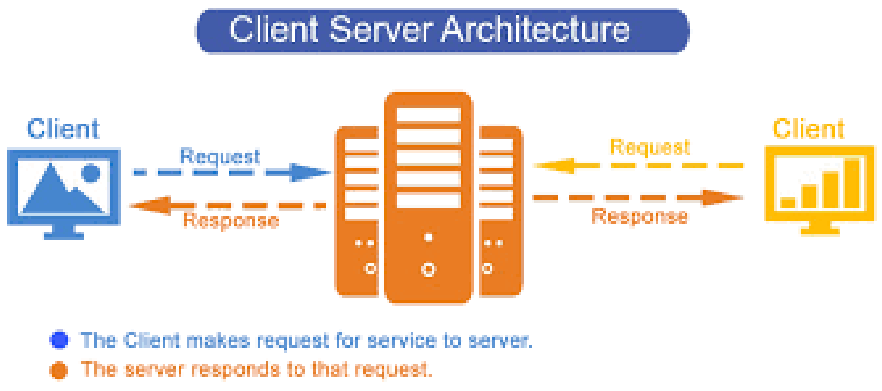

Client Server Architecture
Client
Request
Response
Request
Response
Client
The Client makes request for service to server.
The server responds to that request.

Figure 2.12: Client server architecture

Peer-to-Peer (P2P) is a fully distributed architecture which in contrast to client-server has not a centralized service provider. Peers are both clients and servers themselves, P2P promotes sharing of resources and services trough direct exchange between peers. Compared to a centralized client-server architecture a P2P net scales better and typically does not have a single point of failure.

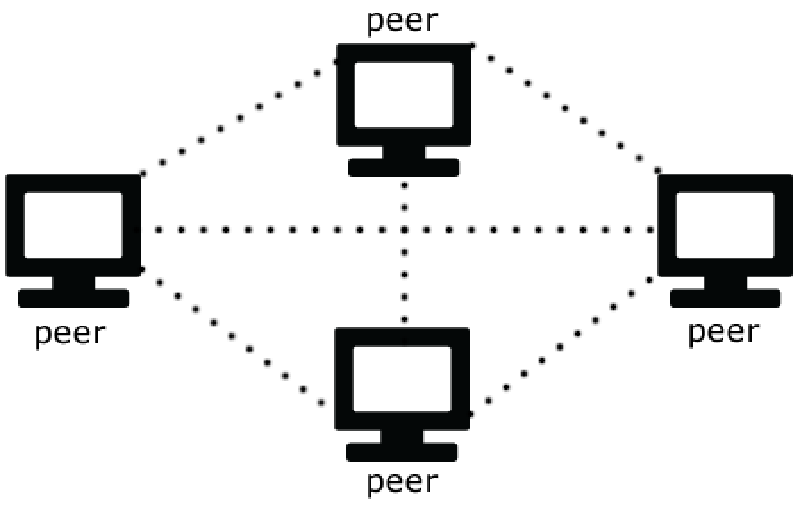


Figure 2.13: P2P architecture

REST style Representational State Transfer (REST) is a style of architecture based on a set of principles that describe how networked resources are defined and addressed.An application or architecture considered RESTful or REST-style is characterized by:

- state and functionality are divided into distributed resources,
- every resource is uniquely addressable using a uniform and minimal set of commands (typically using HTTP commands of GET, POST, PUT, or DELETE over the Internet),
- the protocol is client/server, stateless, layered, and supports caching.

Event based is an architecture in which components collaborate by exchanging information about occurring events. In particular components in the net can *publish* notifications about the events they observe or [subscribe] to events they are interested to be notified about. This architecture can be fully distributed with all the same nodes or can have some semi-centralized nodes which are specialized in computing events or routing messages. Communication is, in this case, purely message based asynchronous and multicast.

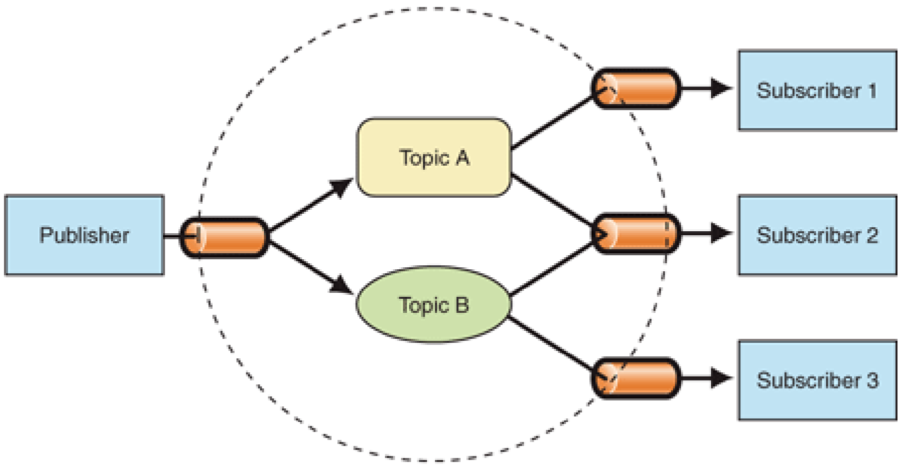


Figure 2.14: Publish-subscribe architecture

2.2.5 Naming

Naming is one of the major issues when building distributed systems, in fact, it is often impossible to know a priori, exactly the addresses and port services of all the components in a distributed network, especially when the system allows dynamic connections and disconnections. It is important therefore, to adopt a naming model or service, to automatize components discovery and connections, when running a distributed system. To understand how naming models e solvers work it is important to introduce some naming concepts in the distributed systems paradigm.
In distributed systems names are used to identify a wide variety of resources such as computers, hosts, files, services as well as users. Names are usually accessed by an *access point* which is a special entity characterized by an *address*. Addresses are just special names which can be used by communications protocol to connect different machines. For this reason it is important to know access point addresses because otherwise it would be impossible to connect components. Dynamic systems let components change access points frequently, so having *location-independent* names is much more convenient than known static addresses which can change during system execution. *Identifiers* such that they never change during the lifetime of an entity, are unique, and can not be exchanged between different entities. In this way, using identifiers, it is possible to split the naming problem in two: mapping a name to the entity and then locating the entity itself. Naming schemes are the solution to the first problem, and the most used ones are:

- *Flat naming*, or unstructured, are simple identifiers represented by random strings of bits.An important property of such a name is that it does not contain any information whatsoever on how to locate the access point of its associated entity [13].

- *Structured naming* are composed from simple, human-readable names, not only file naming,but also host naming on the Internet follow this approach,in fact, flat names are good for machines, but are generally not very convenient for humans to use [13].

- *Attribute based naming* is a way to describe an entity in terms of *(attribute, value)* pairs. Flat and structured names generally provide a unique and location-independent way of referring to entities. Moreover, structured names have been partly designed to provide a human-friendly way to name entities so that they can be conveniently accessed. In most cases, it is assumed that the name refers to only a single entity. However, location independence and human friendliness are not the only criterion for naming entities [13]. Using attribute based naming is possible to give more information about entities or services to be found.

The solution to the second problem is called *name resolution*. Name resolution in the process of obtaining the address of a valid access point of an entity having its name. Name resolution services highly depends of the naming model adopted by a system.
For sake of brevity here are not reported any detail of name resolution systems, but only basic naming notions to understand author's design choices in solving the thesis problem.

2.3 Liquid computing

2.3.1 Definition

The term was coined for Apple's liquid computing feature and refers to a style of work-flow interaction of applications and computing services across multiple devices, such as computers, smartphones, and tablets.
In a liquid computing approach, a person might work on a task on one device, then go to another device that detects the task in progress at the first device and offer to take over that task. In other terms liquid computation is a sort of what is called *ubiquitous computing* which is a model of man-machine interaction in which information elaboration is integrated in everyday objects.

2.3.2 Examples

There are some implementation of this concept in mobile computer science, the most significant are:

- Apple continuity, is a system, developed by Apple, with which a user can initiate a task on one device and end the task on another. For example it is possible to answer a call with a computer without using the phone.

- Google chrome and Gmail, developed by Google, allow users to surf the web and to write email on every available device as if they were using a single device. By registering a Google account chrome can save the navigation history of the user and show it on any logged device. In the same way Gmail saves automatically emails and for example is possible to start writing an email on a desktop pc and then completing and sending that email on a smartphone.

- Microsoft One Drive sync is a system, developed by microsoft to allow users to synchronize file and settings among their devices like desktops, notebooks smartphones and so on.

Chapter 3

Problem Analysis

In this chapter the specific problems of this work will be detailed and analyzed, explaining what are the limits and the constraints the challenge has. The chapter starts with a brief recap, followed by the proper definition of what I faced, while in the last part there is a list of constraints my architecture will have fulfilled in order to have a universal and functional solution.

3.1 Contextualization

In the previous chapter, number 2, I have defined Android OS working mechanism and components, pointing out the main focus on intent generation and resolution mechanism. I have then defined in deep what a distributed system is and should be, explaining connection mechanism architectures and properties.
The Android OS is a centralized operating system designed for a single physical user, to be used on personal mobile devices such as smartphones and tablets. The result of this Google's ideas is that in contemporary society there is a wide spread of Android devices, which now have computing capacity comparable to normal desktops and notebooks. Many people have multiple devices which they use separately: typically they use smartphones for calls and work emails and maybe tablets to easily surf the Internet and play games, but what they can not do is use them together to perform a common task easily. Android, in fact, has not been thought to build a real distributed system, the networking functionalities are designed to exchange messages, and to replace standard personal computers in some task as indeed sending emails. The result is a non collaborative confused cloud of devices, which are connected to the net, but are not really connected themselves to cooperate. Solutions are often partial or proprietary and closed, even if some useful solutions exist.
The idea is let android devices collaborate and cooperate in a *Liquid environment* like the one presented in section 2.3. The fundamental requirement is the implementation of an android service, able to build and maintain a distributed net of android devices over a Wi-Fi LAN (Local Area Network), and then let one, or more devices in that net generate Android intents and distribute them one, or more, of the other devices involved. Thus in this chapter I am considering only Android devices that can be connected in a WiFi LAN.

After this brief recap of what has been said about the Android OS and distributed systems in the state of the art chapter, here I am trying to define with more precision the problem I am going to face: which its constraints and its possible goals are.

3.2 Considered Devices

As anticipated above, I am going to take into account only devices that can be somehow connected to a LAN, but as described in 2.1.5 Android devices are built to be connected to the Internet and most of them comes with a WiFi chip integrated. Another *"little relaxation"* I want to do is linked to the variety of Android OS versions. I want to take into account only devices updated to at least version 4.4 (API level 19). This is due to the fact that starting from Android KitKat (4.4 version) Google brought some important improvements to the libraries of the framework and in addition, according to the Table 2.2, with this choice it is possible to cover the 84% of the active Android devices.
Having done these clarifications, now I am defining the problem.

3.3 Definition

As already said the Android OS is a pretty closed system itself, the intent resolution mechanism shows how it is difficult to let communicate various components inside a single device. On the other hand it is equally true that Android devices are real powerful modern computers and would be great if somehow it could be possible to have a device able to detect other devices in a LAN send data and task to perform in a transparent way and then get back, if necessary, result or data. Let me be more concrete, often in a home environment there are several android devices, whit a distributed intent resolution mechanism it would be possible for example to take a photo from one device with the camera of another one, to generate an intent to open a file on a group of devices simultaneously, to play a video remotely and so on, only by generating intents and then send them to the distributed net. *How can we let multiple android devices act as a single big distributed system?* This is the question that my thesis is trying to answer. My work is a concrete solution, it is about defining and creating a method to distribute android intents from one device to other in a LAN and then let the OS act as usual to manage and resolve them.
So I am trying to let different android devices talk by means of distributing intents using well known architecture: a master component, let me call it *distributed intent generator* acting as client, and a slave component *distributed intent solver* acting as a server. The two components i will realize will be common Android background services registered on the WiFi LAN. Both of these components will result in android applications so that a single device could be used to control others or to be controlled.
In Figure 3.1 is presented how such a system should work once the net is up. The distributed system in figure is a simplification of what the middleware for

distributing intents will do. The architecture will communicate using standard android networking messages that are build on top standard protocols of the ISO/OSI stack.

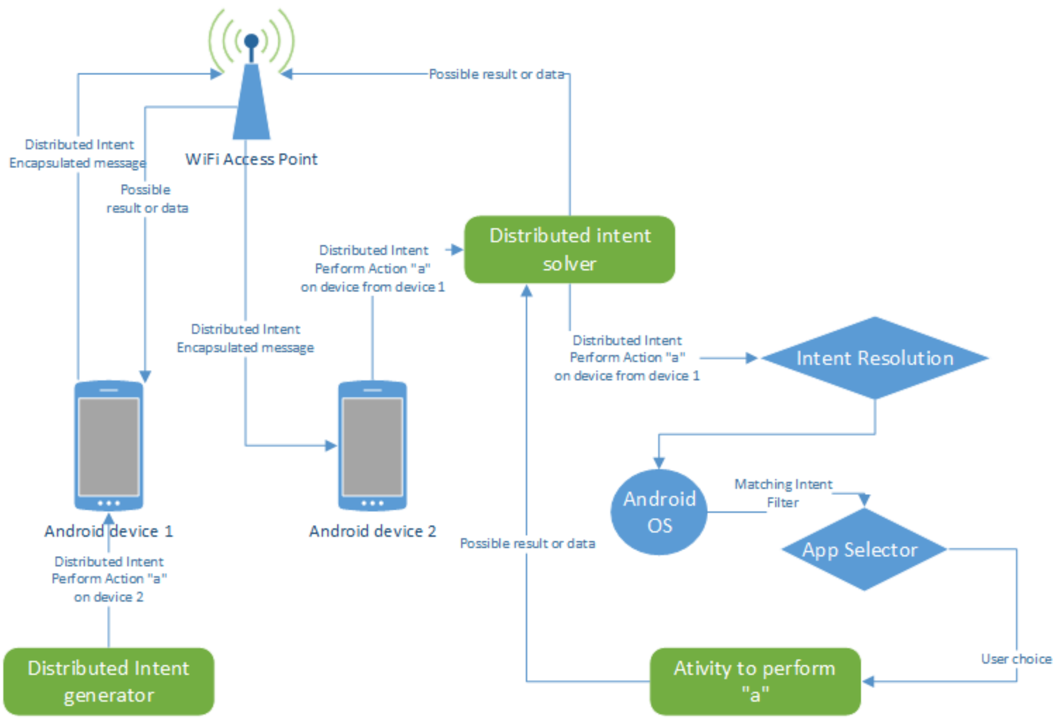

WiFi Access Point
Possible result or data
Distributed Intent Encapsulated message
Possible result or data
Distributed Intent Perform Action "a" on device from device 1
Distributed intent solver
Distributed Intent Encapsulated message
Distributed Intent Perform Action "a" on device from device 1
Intent Resolution
Android device 1
Android device 2
Android OS
Matching Intent Filter
App Selector
Possible result or data
Distributed Intent Perform Action "a" on device 2
User choice
Distributed Intent generator
Ativity to perform "a"

Figure 3.1: Distributed intent resolution

The important point is having a message with a well defined content: it is what the two parts must write and read, so it has to be clear for machines, must be compliant with all the requests of *M2M (Machine-to-Machine) communication*. This type of communications is a constraint of my work and are explained in the next section 3.5.Another important point is let the Android OS work as it is designed for, the main aim of this thesis work is to build a middleware to let distribute native Android intents over the network. This is a new approach to this problem in fact, there are yet some android applications which let the user send stream or data to other devices in a LAN but, with specialized and ad hoc built messages within the same application context, using a mechanism really close to explicit intent resolution. My middleware is supposed to address the problem using a more general approach and a mechanism equal to implicit intent resolution. What I'm doing is create a system to spread any kind of implicit intent and let the OS react as usual to perform the required action. It is not even marginal the choice of the type of network to be used in such a system. Android devices are in fact, usually, mobile devices, and for this reason they can be easily moved from one place to another, so the network must take into account this property dynamically react to continuous changes.
Next sections will properly define all the constraints of the given problem and propose a solution that fulfills them all.

3.4 Probelm scenarios

As already anticipated with the definition of the problem, the aim of this thesis is to give the feeling, to users, that they are working with multiple Android devices as if they were one single distributed operating system. I want to analyze some problematic scenarios an then in the next chapter of the thesis provide, if possible a solution to each specific case.

3.5 Constraints

In this section I would like to list a set of constraints for the defined problem, that become requirements that the solution must meet. The section should be divided into two parts, the first for the requirements of the network, the second for the ones of the Android distributed intent generator and solver. The two sections are actually closely related so here I preferred to keep the two parts together, analyzing the entire middleware structure.
Here is the list:

- *M2M communication:* M2M communication is defined as a communication in which the two interlocutors are not humans. It is a communication completely handled by machines and computers [3]. It can be considered one of the fundamental enabling technologies of this thesis work, it permits object to communicate without humans being involved. In This type of communication the reader of the content is a computer, in this case are Android devices. The content of the messages must be well formed, the middleware must react properly to the event of receiving a distributed intent. So a clear, defined syntax with a well fixed structure must be set in order to make everything understandable to a computer.

- *Transparent:* As already widely discussed a middleware is those which do the *magic*. The proposed solution is intended to be transparent to the Android OS and let it work as usual in resolving implicit intents whether they are distributed or not. Moreover as discussed in the chapter 2, to be more precise in Table 2.3, a distributed system must be transparent at many level, in this case the middleware must act as resources manager and efficiently mask resources access and location.

- *Lightweight:* Another constraint to my system is the fact that whatever system I choose to be the solution it must be lightweight. This is needed because my system will work on a WiFi LAN. Messages must be encapsulated, serialized from one device and transferred in another one to be deserialized and analyzed to be executed. Messages must be as easy as they can because they are very frequent in such a system.

- *Modular:* The implementation of the solution must be modular, this is due to the fact that this middleware is intended to be used as is but also to implement easily other kind of native Android distributed system application.

Having a modular structure facilitates the specialization of its component and make all the middleware more readable and easy to use. In this way Liquid Android can be the substructure of other works.

- *Extensible:* the implemented solution must meet canonical programming principles Extendability is one of the most important properties to take into account when building a computer system, especially when developing a middleware. Liquid Android modules have to be extensible to be improved or adapted to different purposes.

- *Secure:* Liquid Android middleware must meet standard Android security design principles as described in 2.1.4. The implementation must not exceed the limits imposed by the OS, I do not want to break the Android permission scheme and authorization model by *rooting* the operating system, a process with which is possible to perform action as the administrator in Android environment. Rooting Android devices let application overcome the boundaries of standard applications, by letting them read and write data from all the OS. Moreover the middleware operates on mobile devices which usually contains and can manage many sensible and personal data, communications between these devices must be as secure as possible to limit security threats.

- *Consistent:* Data and accessed resources involved in the system must meet consistency requirements. When developing distributed systems consistency is one of the main issue. The implemented solution must take into account data produced during the use of the system and make them consistent according to a chosen consistency model.

- *Scalable:* the system to be implemented has not a fixed number of devices involved in. The chosen network architecture must be able to react according to the changes. Android devices are free to join or leave the network any time, and the system should be able to detect and maintain a dynamic network. Scalability is, in fact, the capability of a system, network, or process to handle a growing amount of work, or its potential to be enlarged in order to accommodate that growth [2].

- *Concurrent:* another important aspect of distributed systems is concurrency. Concurrency is the decomposability property of a program, algorithm, or problem into order-independent or partially-ordered components or units [11]. The implementation of the services must ensure this property to the system. The middleware has to have the capability to handle different requests at the same time and execute task in more than one device simultaneously.

The listed requirements, as already told in some of them, are, sometimes, general, in the sense that they have to be respected for the final product: a global and complete structure that starts from the construction of the network architecture arrives to the user's interaction activities on Android devices. This is because the problem I am facing is very big and complex, and it is transversal to the existing technologies, so the whole system must work properly. Keeping in mind what I have just stated, some of these constraints become fundamental requirements that my system must meet. My work has to be clear for developers to be used for further implementations of native Android distributed systems, but even if it can be less clear to an average user it must be usable to those wishing to try distributed intents with their own devices in a home LAN.

In the next chapter I am presenting my idea, the *Liquid Android* middleware, the so called solution to the given problem, explaining what I have done, my considerations about the situation here faced.

Chapter 4

Proposed Solution

In this chapter the development of the solution will be reported step by step, with some use cases. The chapter starts with a list of solutions already developed, already on the market and he differences between them and my work. The remaining part is composed of two mains sections: the first explains the choice of the so called *container*, the architecture, the type of file, etc. It lays the foundations and describes the limitations for the second part: the definition of the *syntax*, or better the *structure* of what is written inside the container. The two parts are closely related, therefore their relation was taken into account when I made my choice.
The real implementation of the valid solution is left for the next chapter.

4.1 Already developed solutions

A lot of companies have already tried to create a solution as "universal" as possible, but as their main aim is profit they are not really interested in creating a "real" universal solution. Their main goal is including more and more smart objects and making them compatible with their systems. The Web of Things for them is not an arrival point to reach, but rather an obstacle for increasing their profits. Companies are not innovating in the sense of creating a common framework that every vendor can use. They are trying only to enlarge their sphere of influence, not to be a real change in the world. This means companies aim to keep the IoT as final product to offer to users, doing it with some partnerships with the companies which produce smart devices. It is only a matter of time before some exclusive contracts will be signed: if some producer becomes a supplier for only one system, there is no gain for the community, a user has to choose which objects to buy depending on the system he has maybe already chosen and not depending on the specifications or the features of the device.
For instance we can analyze some products, such as *Apple HomeKit*. Apple has built this groundbreaking application with the possibility to integrate devices to control a smart space, in particular a house. The idea is good, the application, in my opinion, is fantastic, but there are some limitations: the application can run only on iOS devices, and this constraint is somehow strict, as already explained in the first two point of the **??** section. Then, as explained here, the only devices

that are compatible are the one which includes a particular protocol, always developed by Apple [**applehomekitprotocol**]. It is called *HomeKit Accessory Protocol (HAP)*, it is closed and vendors have to implement it inside the objects. This second requirement is stricter than what I have stated in 3.3 section, I only "impose" objects to have an HTTP connection and act as web servers: there is no simpler request to be on the web. Here it is different, HAP can work also on Bluetooth Low Energy (LE), but an upper layer is needed.

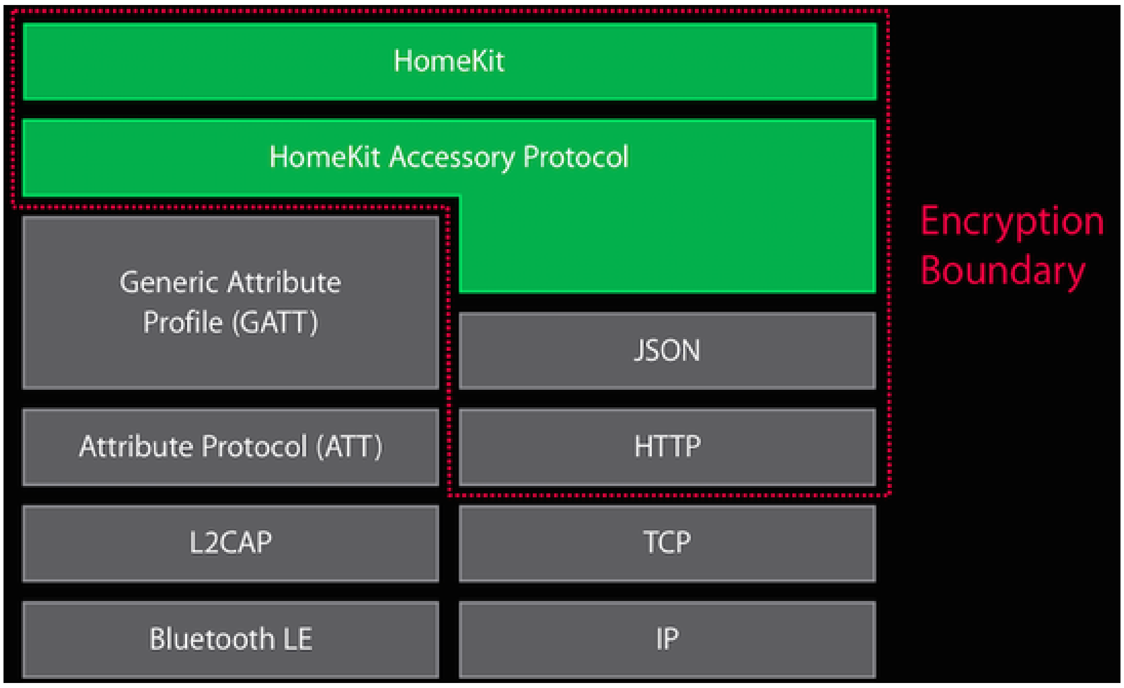


Figure 4.1: HomeKit Accessory Protocol (HAP)

I quoted this solution only to give the reader an idea of what is already existing, but many other systems are present on the market, Google has its system, called *Google Brillo* that works similarly. Brillo is an Operative System (O.S.), obviously based on Android, which must be installed on the smart object. It "violates" my requirements about the liberty of a device concerning hot to reach the web and how to implement underlying layers. Also Microsoft has its solution, it enjoyed the *Allseen Alliance*, an open solution that embraces all the levels of the protocol stack, using ad hoc developed layers.
All the solutions I have very briefly listed here are only some of the ones the market today offers. But they have a different purpose, they wants the devices mounting an operative system, a protocol, etc. This still remains in the situation explained in chapter 2, a war fought by different companies or alliances, leading the world to a myriad of different and incompatible solutions: it is more an attempt to enlarge each own IoT, respect than the creation of an open solution for a common widely resource like the web. Now it is the moment to start with my reflections about the given problem comparing the available paths to reach a solution.

4.2 Choice of the *container*

To better explain what I consider container it is important to understand the playground to my work. As said in the previous chapter, 3, I am trying to fulfill the "horizontal" part of the connection in the stack, staying in layer 7, the application layer. Using already developed and operating tools, and respecting all the above listed constraints I am going to make the communication between WoT and IoT "HTTP ready" devices possible. I will now present alternatives to assure communications, choosing the one that better fits my requirements. The choice of the so called container is very important: it puts boundaries in the structure/syntax definition, so it is essential to understand pros and cons of each candidate.
I am searching for technologies that permit clients and servers to communicate, operating on the same network. The network is composed of three main actors: the user's client which is the web application opened, for instance, on a smartphone or a pc; the web server which it is the real application and it is on a machine which it behaves as a server for users and as a client for the smart objects; the objects, that have an end point on the HTTP protocol and behave as servers for the web server which asks information periodically.
What we need is a *Web Service (WS)*. To understand what a WS is, there is the necessity to understand what we are doing and what we want to accomplish.

4.2.1 Web Service (WS)

The web today is a sort of container of more than hyperlinks, it is a distributed application platform. If it is distributed data should be exchanged among nodes. What enables this exchange is the Web Service. A WS can be defined as a software component that permits data to flow among different applications (written in different programming languages) that runs on different operative systems, installed in different nodes of the network [**alonso2004web**]. This mechanism does not put any limitation on the type of the application developed on the web and it is perfect. It does not affect the internal implementation of a web application, it is completely independent. A web service exposes some services, that can be "called" remotely to the other nodes of the network These services are often called *APIs*, that stands for *Application Programming Interfaces*, and they are particular functions that the developer of an application chooses to make reachable from others. It is possible to call the APIs through messages, more specifically W3C has standardized only one way to do it, through HTTP protocol. The WS has obviously some advantages and disadvantages that I will list.
Advantages:

- Interoperability among different software applications that run on different hardware platforms is possible.
- Data format can be considered "textual", that is easy readable both for machines and humans.

- Using HTTP for the transport of the message Web Services do not need any change in security rules of the firewalls of the nodes of the network.
- Web services are completely independent one from another, so they can be combined in a more complex and complete service offered to the user.
- There is no need to rewrite applications already existing to make them compatible to WS. They are completely independent also from modification done successively.

Disadvantages:

- Consolidated standards for critic applications, such as distributed transactions, do not yet exist.
- Some other alternative approaches for distributed computing can have better performances in some situations (Java RMI, CORBA, DCOM). They are briefly discussed later.
- They can "avoid" firewall controls and that can potentially be dangerous.

The main reasons of the wide adoption of Web Services are, as said, firstly, the "decoupling" between the service itself and the application behind it, without worries about modifying or rewrite one of the two sides, they are completely independent. Secondly, it uses HTTP over TCP on the 80 port, the one left (almost) always opened in each system so as to enable to surf the net even company networks that often have limitations for security reasons.
The Web Services have two main different implementations, *SOAP* and *REST*. These two approaches will be examined in the next subsections, now I will briefly focus on the alternative methods respect to these two.
The alternatives to Web Services are not taken seriously into account because they cannot be considered universal, as they are too closely related to a specific language or a set of languages. For example, *Java RMI* stands for Remote Method Invocation and it enables to invoke a function on a remote object. Methods must be public and known by everyone. But it works only among Java sandboxes, so the application must be written in the Java language. It is a strict requirement for the whole web and it cannot be used in my work. *CORBA (Common Object Request Broker Architecture)*, for instance, is another standard that can work with a set of different languages, which means not all the languages are accepted, but an intermediary is needed, called broker, which reads objects written in a special language that is IDL (Interface Description Language). And the translations between IDL and the specific languages are what makes CORBA compatible only with a defined set of programming languages. In any case this particular technique requires all the nodes of the networks to support it, an HTTP connection on 80 port is more and more simple.
These two examples, obviously, do not cover all the alternatives, but they are quoted to explain how the Web Services and their features are the most frequently used and effective solution. The next sections examine SOAP and REST and explain how and why I took my decision and reached my solution.

4.2.2 SOAP protocol

SOAP (Simple Object Access Protocol), as the name says, is a protocol that permits to call remote procedures (procedures are methods). This is enabled by an exchange of SOAP messages. SOAP is a member of the *Remote Procedural Call* protocols family. SOAP is a standalone protocol that must be embedded in other protocols in order to surf the network and reach the proper node. The *W3C* has standardized only HTTP to be the protocol which embeds SOAP, even if it is possible to embed also in the STMP (Simple Mail Transfer Protocol) one. SOAP can be viewed as a protocol that stays on top of the HTTP one and uses it as transport to reach every part of the network. It is older than its "opponent" REST, it was originally created by Microsoft and then submitted to the Internet Engineering Task Force (IETF) where it was standardized [**soap**].
Once it is understood that the fact that SOAP uses (mainly, but it is my case so I consider it a "standard") HTTP as a transport layer, we have to analyze the content of the message SOAP sends and receives. SOAP messages are based on the XML language that will now briefly explained.
Starting from scratch, *XML (eXtensible Markup Language)* is a language of markup, it means it has a syntactic mechanism to define and control the meanings of what is written inside. It defines the format of file .xml that can contain information which is possible to exchange on the network. It is composed of a hierarchical structure of tags, which can contain information (called also #PCDATA, "Parsed Character Data") or other tags, it also is considered extensible because it is possible to create custom tags of any type only declaring them. As a small example, I report the following XML file, describing a list of users which can be, for example, the export of the contacts on a smartphone.

Listing 4.1: XML file example

```xml
<?xml version="1.0" encoding="UTF-8"?>
<users>
    <user>
        <name>Jane</name>
        <surname>Doe</surname>
        <number>+393333333333</number>
    </user>
    <user>
        <name>Jack</name>
        <surname>Sparrow</surname>
        <number>+394444444444</number>
    </user>
</users>
```

The first line is called prologue and it is only a declaration of the XML version used and the encoding UTF-8 to interpret data correctly. The root tag, which is unique, is "users", that is a list of "user", each user is composed of a name, a surname and a number. The tags are formed by <> with in between the name of the tag. In this case tags are balanced: a tag is opened, then there is the content

and finally it is closed. Also the nesting of tags is respected: opening "user" and then "name" I have to close the last one opened so I close "name" and then "user". These three properties (prologue, root that must be unique, balanced tags), if present, define a Well Formed XML. Having a WF XML it is possible to add a *DTD (Document Type Definition)* file that contains rules to write a particular type of XML. DTD is out of our way, so I will not explain it in details. The only important thing is that it contains rules for writing XML, defining which elements can have sons, and type of information contained (link, string, etc). Another more recent type for the definition of the structure of an XML file is the *XML Schema*, called also *XSD, XML Schema Definition*. It is properly an XML file that defines a XML file and it supports datatypes (while DTD does not), and more generally it supports more options for defining precisely all the fields of the XML. If an XML file is Well Formed and it follows a DTD or XSD specifications, the XML file is called Valid.
In particular, a SOAP message is composed of a root tag called "soap:Envelope" that has two sons: "soap:Header" and "soap:Body", similar to the HTML structure. The header is optional while the body is mandatory. The header contains meta-information regarding routing, security, user identity, transactions etc. Two particular fields are remarkable: "MustUnderstand" that must be put equal to 1 if we want to oblige the reader to parse and read the header, because it contains vital information, for instance how to decipher a message. "Actor" contains the address of the recipient, so the intermediate endpoints can avoid to read the header. The body contains information, called payload. The payload has to follow a schema defined with a XSD, in order to assure that the SOAP message is Valid. The structure of the SOAP message just described is completely independent from the underlying protocol, HTTP, STMP, etc. that is used for transport [**soapMessage**].

Listing 4.2: SOAP message example

```xml
<?xml version="1.0" encoding="UTF-8"?>
<soap:Envelope
        xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
        xmlns:xsd="http://www.w3.org/2001/XMLSchema"
        xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">

  <soap:Header>
    <ns1:RequestHeader
         soapenv:actor="http://schemas.xmlsoap.org/soap/actor/next"
         soapenv:mustUnderstand="0"
         xmlns:ns1="https://www.google.com/apis/ads/publisher/v201605">
      <ns1:networkCode>123456</ns1:networkCode>
      <ns1:applicationName>Babel Framework</ns1:applicationName>
    </ns1:RequestHeader>
  </soap:Header>

  <soap:Body xmlns:m="http://www.xyz.org/quotations" >
      <m:GetQuotation>
         <m:QuotationsName>Apple</m:QuotationsName>
      </m:GetQuotation>
   </soap:Body>

</soap:Envelope>
```

The above file contains an example of a SOAP message that requires the value of Apple quotations to another node in the network. It is possible to identify all the elements previously described.
But, how can it be possible to know the right syntax of a tag to put in the "soap:Body" to have back a precise element? The *WSDL (Web Services Description Language)* describes how the Web Services work, WSDL can be seen as a public interface of a Web Service [**curbera2002unraveling**]. The WDSL is an XML file separated by SOAP messages, that is a sort of "handbook" of how to use the Web Service. It is mainly composed of three sections: "what" can be used, which means the operations that is possible to call through the network; "how" it is possible to use the service: the type of the protocol to use, the type of both input and output messages and the bindings of the service; "where", the endpoint to which it is possible to require the service, it is an URI. The WSDL can be divided also in another way: logic and concrete sections. The logic part contains interfaces, operations and messages, while the second defines transport, bindings and endpoints. The current version is the 2.0 released in 2007 and it is a standard for the W3C. In the next listing I will give a example of WSDL, it is only an simple example to provide the reader with a more concrete idea of what we are talking about.

Listing 4.3: WSDL file example

```
<definitions name="HelloWorldService"
   targetNamespace="http://www.examples.com/wsdl/
      HelloWorldService.wsdl"
   xmlns="http://schemas.xmlsoap.org/wsdl/"
   xmlns:soap="http://schemas.xmlsoap.org/wsdl/soap/"
   xmlns:tns="http://www.examples.com/wsdl/
      HelloWorldService.wsdl"
   xmlns:xsd="http://www.w3.org/2001/XMLSchema">

   <message name="SayHelloWorldRequest">
      <part name="firstName" type="xsd:string"/>
   </message>

   <message name="SayHelloWorldResponse">
```

```xml
      <part name="greeting" type="xsd:string"/>
   </message>

   <portType name="HelloWorld_PortType">
      <operation name="sayHelloWorld">
         <input message="tns:SayHelloWorldRequest"/>
         <output message="tns:SayHelloWorldResponse"/>
      </operation>
   </portType>

   <binding name="HelloWorld_Binding" type="tns:HelloWorld_PortType">
      <soap:binding style="rpc"
         transport="http://schemas.xmlsoap.org/soap/http"/>
      <operation name="sayHelloWorld">
         <soap:operation soapAction="sayHelloWorld"/>
         <input>
            <soap:body
               encodingStyle="http://schemas.xmlsoap.org/soap/encoding/"
               namespace="urn:examples:helloworldservice"
               use="encoded"/>
         </input>

         <output>
            <soap:body
               encodingStyle="http://schemas.xmlsoap.org/soap/encoding/"
               namespace="urn:examples:helloworldservice"
               use="encoded"/>
         </output>
      </operation>
   </binding>

   <service name="HelloWorld_Service">
      <documentation>WSDL File for HelloService</documentation>
      <port binding="tns:HelloWorld_Binding" name="HelloWorld_Port">
         <soap:address
            location="http://www.examples.com/SayHelloWorld/" />
      </port>
   </service>
```

```
</definitions>
```

Giving a brief description of the WSDL file, the tag "message" contains the type of message that the service has both in input or output and "name" indicates the parameter of the message, the tag "portType" describes the full available operation, indicating also which is the input message of the service and which one is the output, these two tags together are we what have called "what" previously; the tag "binding" is the "how", it explains that the service is reachable with the SOAP protocol and specifies the body of the message; finally, the tag "service" indicates the endpoint to which is possible to request the service, it is the "where" section previously defined.
Back to SOAP, one thing remains to be said, it is highly extensible, in particular some modules can be added: the term *WS-** stands for Web Services, but the * indicates all the possible ones. An extension is a variation of "something" in the SOAP message to emphasize a specific feature. Lots of extensions exist: for instance, WS-Security (WSS) is one concerning security, it can be used for some particular application where an identification or even authentication is required, it becomes less useful for open application. It guarantees, for example, end-to-end security, identification tokens and many other features.

4.2.3 REST paradigm

The SOAP protocol and all its "environment" are only the first alternative we have to enable Web Services. The second one is the architecture called *REST (REpresentational State Transfer)*, it was conceived for systems of distributed hypertext, as the web is today [**fielding2000representational**]. In fact the World Wide Web is the most successful field in which the REST paradigm is used, but not the only one. The first thing to specify is that while SOAP is a particular, well defined protocol, standardized with a specific set of rules to follow, REST instead is a set of guidelines, a paradigm as just said, for the realization of a "system architecture". The word REST, indicating a "way to do things", can be considered the opponent of the term Remote Procedure Call (RPC), that indicates the procedure previously described, rather than SOAP, but, a unique implementation of a RESTful device does not exist I am putting them on the same level here. Note that a service implementing the REST paradigm is called *RESTful service*.
Basing our analysis only on the web it is possible to state that REST is based on the concept of transmitting information over HTTP without the use of an upper optional layer such as CORBA, SOAP or the cookies used in websites nowadays. REST paradigm is based on principles that the web today knows very well, but they are somehow reinvented to be part of a Web Service. Firstly we have to define what can be considered *resource* for the web:

- A resource is every web element that had an elaboration. It is possible to compare a resource to an instance of an object in the Object Oriented programming paradigm.

- A resource can contain the state of an application or the functions it provides.
- A resource is uniquely identifiable by a string called *URI (Universal Resource Identifier)*, a URI can be seen as the link to put together more than one resource.

Having defined what a web resource is, the REST paradigm follows some other principles to exchange information among nodes of the network. The resource is what permits the sharing, but even the exchange process has to follow some guidelines respect to REST principles. The resources are shared as a common interface to allow the transfer of states among resources. The main features of the transfer are:

- a fixed set of well known operations.
- a fixed set of contents, maybe with a particular request code.
- a protocol, that itself has to be:
  - client-server: the division is strong, every part has its role, for instance, the client has no worries about saving information while the server has no worries about the graphical interface. If the interface that links them remains the same it is possible to modify them separately.
  - uniform interface: client and server need a homogeneous interface. The two parts can evolve separately from the interface.
  - stateless: no context is saved in the server, every request coming from the client has all the information needed to serve it.
  - cacheable: the client can cache answers, but they have to declare if they are cacheable or not in order to prevent the use of wrong and invalid old answers. On the other hand the cache can reduce the number of client-server communications, increasing performances.
  - layered system: there is no only one server, it is possible to introduce some middleware servers to improve scalability with load-balancing or distributed caches. In addition the multi-layer models enables to introduce more secure mechanisms, isolating the information from external attacks.
  - code on demand (optional): servers can send executable code that the client will interpret or compile, such as JavaScript.

Now that the main features have been presented, I will briefly informally describe the full procedure of a RESTful service. Knowing a source of information (the resource), through the URI, the client can make a request and the server can "listen" what is requested. This communication happens through a standard interface (for example HTTP protocol). In this way representations of the resource can be exchanged: receiving the request the server can answer in multiple ways, without knowing the "past story" between the two parts. There can also be

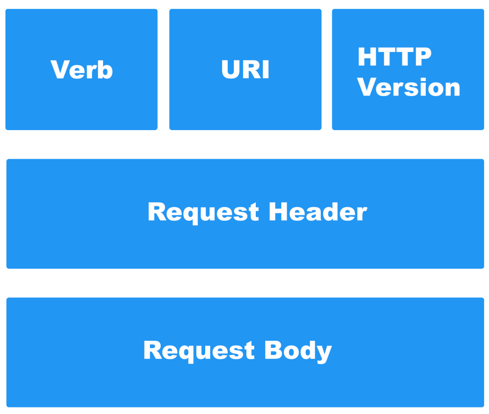
the intermediation of middleware components, proxies, firewalls, etc, this does not affect the final result. The only thing the client needs to know is "what" is returned by the server: the format of the file is very important, the client needs to be able to process it once received. Typically the format is a HTML, XML or JSON file containing the information but answers, for instance, may also be given with a picture.
The use of HTTP makes requesting and interacting with the information required very simple: this protocol provides a set of primitives, functions implemented directly inside that can be used by everyone. REST uses four of these verbs: *GET, POST, PUT* and *DELETE*. For example, the state of service can be obtained performing a HTTP GET to the URI, while in a not RESTful service we can custom methods, with arbitrary names depending on the implementation. In addition, one of the most important things is that HTTP verbs are 1:1 mapping to *CRUD* operations. CRUDs are the fundamental operations that a user can execute on a resource. (More generally four actions must be implemented in a RESTful application, in a relational database and in a document management application to consider them "complete").

Table 4.1: Mapping between CRUD operations and HTTP 1.1 verbs.

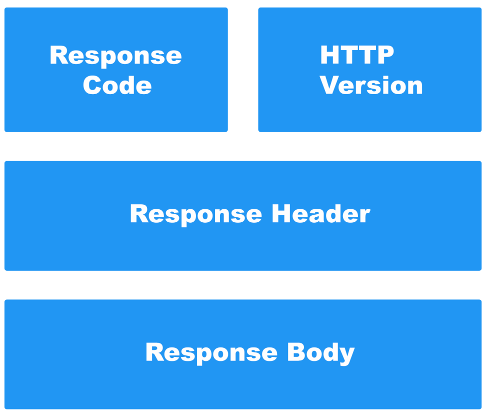
HTTP Verb	CRUD Operation	Description
POST	Create	Create a new resource
GET	Read	Obtain an existing resource
PUT	Update	Update or change the status of a resource
DELETE	Delete	Delete a resource

In this way the HTTP protocol can cover all the possible actions a user can perform on a resource. This is one of the strengths of the REST paradigm.
At this point we have described what REST means, how it works and how it covers the operations needed to handle a resource. Now we will focus on the representation of this last component: what comes to the client is never the resource itself, it is always a representation. As said before there are no constraints on the type of file that is going to represent the resource on the client side, anyway it is better to uniform or, better, circumscribe the number and types of file that a RESTful service outputs. If the servers offers more than one representation it is possible for the client to choose one, indicating it in the "Accept" field of the request message. For example, a browser, when we go to a particular website, is doing an HTTP GET with the predefined "Accept" field equal to "HTML". In this case we have a Web UI, with all the graphical elements, pointing to the same page, changing the "Accept" to "JSON" we have a Web API. Following the REST principle, we can construct different architectures using the same URI, the same resource but changing its representation.
In the following pictures I am going to quickly describe HTTP messages, requests and responses, to have a full comparison with SOAP messages. Then a description of each sector of the message is provided.

The HTTP Request message is composed of main 5 sectors:



(a) HTTP Request



(b) HTTP Response

Figure 4.2: HTTP Messages

- Verb- Indicate HTTP methods such as GET, POST, DELETE, PUT etc.
- URI- Uniform Resource Identifier (URI) to identify the resource on server
- HTTP Version- Indicate HTTP version, for example HTTP v1.1 .
- Request Header- Contains metadata for the HTTP Request message as key-value pairs. For example, client (or browser) type, format supported by client, format of message body, cache settings etc.
- Request Body- Message content or Resource representation

An HTTP Response message has four major parts:

- Status/Response Code- Indicate Server status for the requested resource. For example 404 means resource not found and 200 means response is ok.
- HTTP Version- Indicate HTTP version, for example HTTP v1.1 .
- Response Header- Contains metadata for the HTTP Response message as key-value pairs. For example, content length, content type, response date, server type etc.
- Response Body- Response message content or Resource representation.

The stateless communication is done to maintain scalability inside the server, an open connection or session is a waste of energy and memory space: if too many requests come together the server can crash, it is the base of a DDOS attack for not RESTful services.

4.2.4 Comparison and choice

We have discussed in an appropriate way the two main candidates for the given problem. Here I would like to list pros and cons of both solutions and then choose which container to use, in particular the pros of a system can be considered the lacking items of the other, in the sense that if one feature is on a list it means that it is exclusive of that architecture:

- REST is generally easier to use and is more flexible:
  - No expensive tools require to interact with the Web service
  - Smaller learning curve
  - Efficient (SOAP uses XML for all messages, REST can use smaller message formats)
  - Fast (no extensive processing required)
  - Closer to other Web technologies in design philosophy
- SOAP is definitely the heavyweight choice for Web service access:
  - Language, platform, and transport independent (REST requires use of HTTP)
  - Works well in distributed enterprise environments (REST assumes direct point-to-point communication)
  - Standardized
  - Provides significant pre-build extensibility in the form of the WS* standards
  - Built-in error handling
  - Automation when used with certain language products

Taking a look at the points listed above, I would remark how the pros of the REST paradigm match some of the requirements already listed in 3.5. Efficient and fast were two of the main characteristics needed by our system. Then the fact no expensive tools are needed is another important point, developing a sort of framework for third-party applications. Another advantage of REST is being "language independent". In addition it can be chosen only as "container", leaving the choice of the type of file free, even if we stated that it is better to limit the formats of file sent on the web. As far as SOAP advantages are concerned, it is important to underline how the fact it is independent from HTTP (while REST is dependent) is not a problem because we are talking about the Web of Things, we are supposing to put everything on the web, and the HTTP protocol is one of web's fundamental parts. The only point that can tilt in SOAP direction is the fact that SOAP is standardized while REST is not, it is a set of guidelines, not a well defined structure [**pautasso2008restful**].
As the reader can guess, the choice for my system is the REST paradigm. Despite the fact it is not standardized, REST provides a set of easier "rules" to build and develop a framework easily. The not-standardized part is what I am going

to define in the next section of my thesis. Basing my own architecture on the HTTP messages and REST paradigm, the choice of the file surfing the web is still undecided, and the universal syntax I propose is still to be created.

4.3 Structure definition

This section is intended to define the format of file of my REST solution, and then the syntax inside it. As previously said, every format of file can be embedded into HTTP body and sent on the internet but it is a good habit to limit the number of circulating formats. In particular we can identify what is needed for our problem, restricting the choice.
We need to send to an application, a control center, the description of a smart space, in order to permit the user to control everything. The heterogenous elements are collected with a sort of "discovery", while in my application some "plugs" for particular chosen protocols are created.

4.3.1 Available alternatives

So we have to send descriptions of objects, the descriptions are composed of strings and numbers. It is possible to identify three main formats to send this type of information: HTML, XML and JSON.

- *HTML:* the first format is the classical building block of a web page, it is a language that contains graphical elements, it is created for the web and it is in line with our intent but it is intended for humans, in particular for M2H communications, the final recipient is a human being. This doe not match our requirements: we need, as explained in 3.5, a easy readable language but principally for a machine, my work needs to be a framework, something that links objects of the Internet of Things and the final UI the user will see. For this reason I am going to eliminate from the list of eligible candidates the HTML opportunity. It is the developer that will use my work as input to use, almost surely, HTML as language to speak to people.

- *XML:* this language is approximately suitable for my purpose, it has all the credentials to be the choice, but it can be considered so much verbose and heavyweight compared to JSON. Anyway I am not going to deepen XML because it is already been done in 4.2.2, explaining what kind of language SOAP uses.

- *JSON:* JSON stays for *JavaScript Object Notation*. It is a language created for data exchange in a client-server architecture. It is the choice I have made, and in the following subsection there is a full description what it is, how it works and above all how it can fit perfectly my requirements for the thesis.

I chose JSON for its lightweight, simplicity in writing and reading and also because there is a proposal of W3C to elect JSON to the official language for IoT and WoT. Firstly, I will discuss all the features of JSON, then I will do the same thing for one of its extensions *JSON-LD*, I will present the W3C proposal and finally my solution, remarking what changes respect to others already developed.

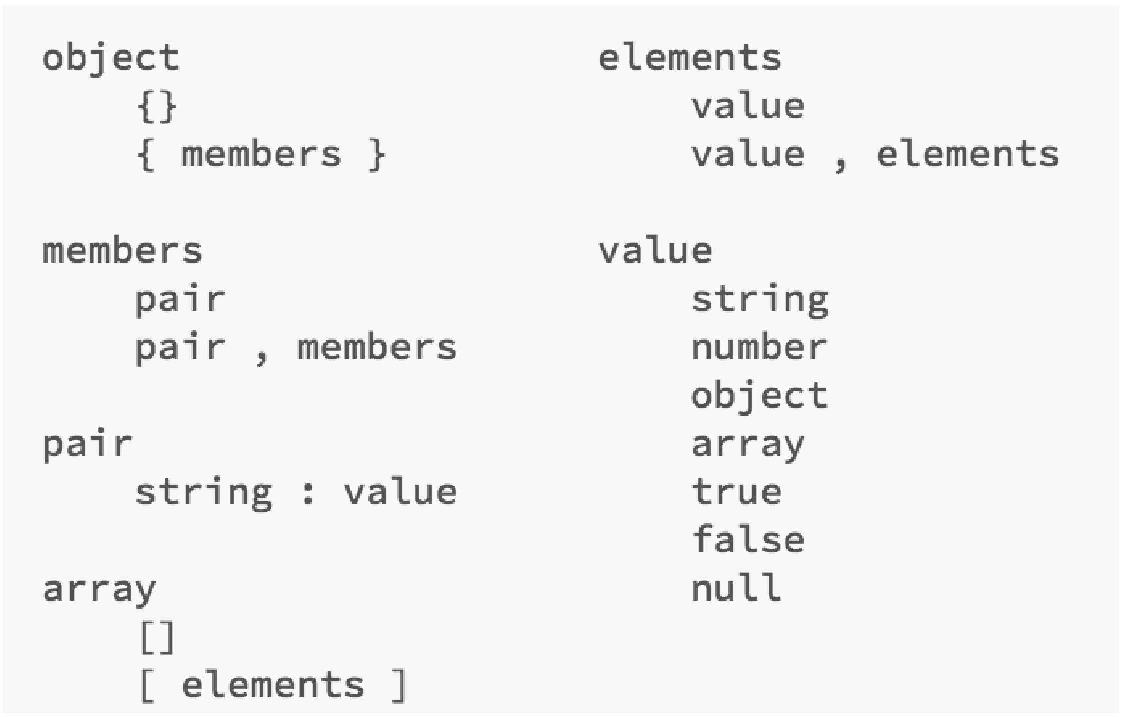
4.3.2 JSON

JSON (JavaScript Object Notation) is a lightweight data-interchange format. It is easy for humans to read and write. It is easy for machines to parse and generate. It is based on a subset of the JavaScript Programming Language, standardized in December 1999. JSON is a text format that is completely language independent but uses conventions that are familiar to programmers of the C-family of languages. These properties make JSON an ideal data-interchange language. **[jsondef]**
It is based mainly on two types of structures:

- *Key/Value pair set:* it can be considered an object of an Object Oriented programming language. It is "contained" by a left () and right () curly brace, each element of the set is separated from others with a coma (,) and it is composed by a *key*, that is a string, followed by semicolon (:), followed by the *value*.

- *Collection of elements:* it can be considered an array, but it covers only *values*, in the sense that in an object, we can define a key, write the semicolon but the values associated to the key are multiple, so they are put in an array. Syntactically they are composed of a left square bracket ([), values separated by commas (,) and after the last value there is a right square bracket (]).

It is important to know what can be assigned to the *value* field. A *value* can be an array, as just said, a string, a number, a *boolean value* (true or false), *null* or another object, constructed as above. This means that nested structures are allowed in JSON format. String are wrapped in double quotes (""), using backslash escapes, empty strings are allowed. The concept of the string here is the same of Java, for instance.
While XML can be considered a markup language, JSON is more a format created for exchange of data. In both language there is no concept of binary data, so the developer has to convert data from the binary format while writing (eg. an integer into a "textual form").
As for XML, a "schema" exists: for XML is called XSD, while here simply *JSON data schema*. It can be used to validate JSON data. As in XSD, the same serialization/deserialization tools can be used both for the schema and data. The schema is self-describing. Anyway it is not a standard like XSD, but only an "Internet Draft (I-D)" proposed by IETF (Internet Engineering eTask Force), in order to become standardized.
In the above picture I am going to report in graphical way what has just been described, the syntactic rules to compose a JSON document, in order to give the reader a easier way to understand the format.



```
object                  elements
    {}                      value
    { members }             value , elements

members                 value
    pair                    string
    pair , members          number
                            object
pair                        array
    string : value          true
                            false
array                       null
    []
    [ elements ]
```

Figure 4.3: JSON syntax rules

JSON format is both *M2M* and *M2H/H2M* constraints compliant, and also *easy readable* (and writable). Having these properties we can also state is *fast*: both machines and humans are quick in doing actions on it. It is also *lightweight*, in particular respect to XML, being less verbose and less depending on open-closed tags. Finally, as it is possible to see from the above picture it is *modular* and *extensible* with the possibility to nest levels.

4.3.3 JSON-LD

JSON-LD stays for *JavaScript Object Notation for Linked Data* and it is intended to be an extension, an evolution to the JSON: it brings the web to a semantic level. To understand what is the *Semantic Web*, I have to firstly explain what are *Linked Data*.

Linked Data and Semantic Web The internet is seen as a network composed of nodes that are "bare metal" objects: computers and servers principally, or smart objects. The web, in the same way, is a network, but it is composed of nodes that are websites or web applications. These nodes are linked, with URIs, as widely explained. While the humans can understand what a link stands for, based on where is put in a page or which keyword is put near it. The machines cannot have this idea, for them a link is simply a reference to another "portion of the web", another web page to download. To make the machines understand what a link is and what represent in that particular context, there is the need to construct linked data. Linked data are simply a way to make the machines conscious of what they are facing: in this way also computers can have a global

vision of the web as a graph, almost connected, understanding the relations existing among different pages or applications. If, for example, we define on the web the concept of human being and the relation "marriedTo", the computer can know that the the object of the relation is another human being, so it can expect some type of data and it can raise an error if, for instance, the received type is a cat. This understanding can lead, for example, a computer to be more and more precise and capable of answering complex queries like "Who is Thomas father?": knowing the relation "father", the machine has only to follow the link provided to get and show the answer. A semantic cognition is what modern search engines are trying to reach.
Meta-data is what permits the recognition, like a index for a library: there you can find all the useful information to catalogue the real information, the books. Here is the same, meta data, specified and filled in the HTML page are what permits the computer to know the relations existing among what it has already downloaded and what it can reach from there.
If the web, a complicated graph, has the possibility to be understood by a machine, we are talking about semantic web. A web with a with a consciousness of itself. **[bizer2009linked]**
I will now report a figure, explaining graphically the concept of semantic web, using *RFDa (Resource Description Framework in Attributes)* syntax. RFDa is a W3C Recommendation that adds a set of attribute-level extensions to HTML, XHTML and various XML-based document types for embedding rich metadata within Web documents. Anyway RFDa is beyond our purpose so it is not explained in depth.

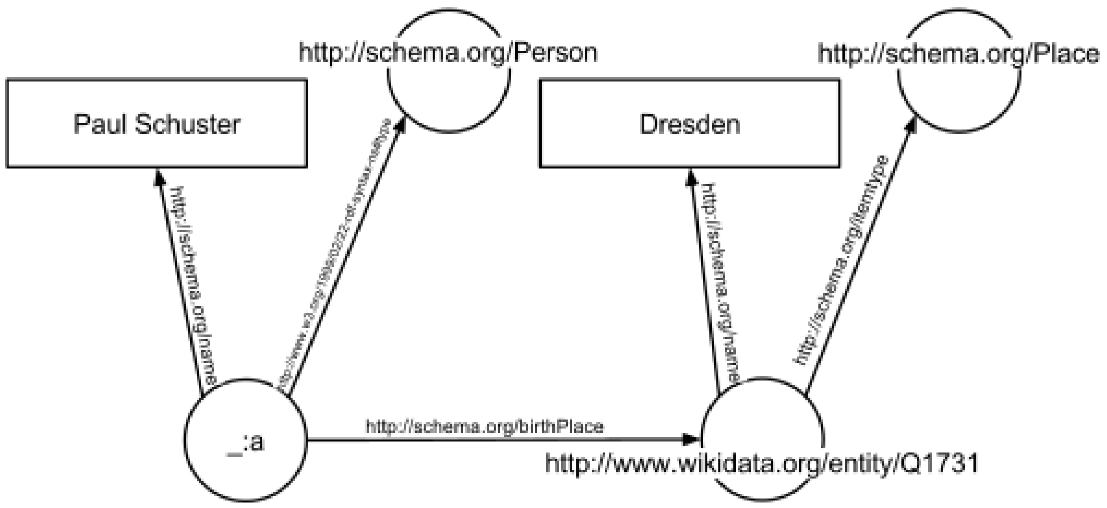

http://schema.org/Person
http://schema.org/Place
Paul Schuster
Dresden
http://schema.org/name
http://www.w3.org/1999/02/22-rdf-syntax-ns#type
http://schema.org/name
http://schema.org/itemtype
_:a
http://schema.org/birthPlace
http://www.wikidata.org/entity/Q1731

Figure 4.4: An example of semantic web

The node here called "_:a" is a node of type "person", a URI (`http://schema.org/Person`) defines what a "person" is. The "person" here has two different properties: "name" and "birthPlace". The "name" property is a string ("Paul Schuster"), a "terminal" (because it is not expanded, identified by a rectangular shape) property of the category "person". The property "birthPlace", on the other hand, is not a "terminal one", identified by a circle shape. It is a "place", another web identity. For this reason it has its own definition with another URI (http://schema.org/Place) and it can have others properties (here not reported) to link a "place" to the remaining rest of the web.

Having given a first explanation of what linked data and semantic web are, we can now proceed to explain JSON-LD and its features useful for my purpose. JSON-LD is a type of document, coming from the JSON, that keeps its structure and its syntax, explained in 4.3.2, but it adds some keywords in order to be part of the semantic web, and to better describe a smart space. In particular the JSON-LD document uses the concept of *@context* as starting point. The @context can be explained as a context of a normal conversation: speaking with someone I have some external elements that help the interlocutors to understand each other, the environment, the place, the weather, etc. The concept is the same, trying to contextualize a conversation between two machines. Here the context maps the *IRIs (Internationalized Resource Identifier)* (more general URIs, using Unicode instead of ASCII) to *terms* defined in the document. Terms are case sensitive and any valid string that is not a reserved JSON-LD keyword can be used as a term. Then, in the rest of the document, we can refer to a particular definition given by the IRI, such as "place", with the term, without the need to map it every time. A @context can be defined internally, mapping explicitly every term to an IRI or can be defined online somewhere, in this case it is considered external.
The new format does not bring only the @context keyword: some others keywords are fundamental to make the web a semantic graph for a computer. The tag *@id* is introduced to correctly identify nodes inside the web, the @id component contains the place, in form of IRI, where the representation of the resource, and in particular of the node, is. The @id tag can be considered the "arrow" the parser has to follow in order to retrieve the node of the graph. @id is not pointing to a definition of what the resource is but the real representation of it.

Listing 4.4: JSON-LD: @context, @id example

```
{
  "@context": {
    "name": "http://schema.org/name",
    "homepage": {
      "@id": "http://schema.org/url",
      "@type": "@id"
    }
  }
}
```

Reading the above listing 4.4 it is important to point out that in the @context two terms have been defined, "name" and "homepage", in particular the latter one uses the @id tag to point to the resource and @type that is explained in the next paragraph.
Another important tag, as already anticipated above, is *@type*, it has a double meaning: it can define the type of the node, it usually points to an IRI containing the formal description of a type of node. The other use of the @type tag is to define the type of a value: in this case it is used with the tag *@value* outside the

@context, or inside it defining a term without the need of @value. What is bind to a value type can be a type defined externally, always a IRI helps doing that, or a native JSON type: in this case there is no need of an external link, the JSON parser already knows how to handle it.
Type coercion is another feature which deserves to be explained: it allows someone deploying JSON-LD to coerce the incoming or outgoing values to the proper data type based on a mapping of data type IRIs to terms. Using type coercion, value representation is preserved without requiring the data type to be specified with each piece of data. Type coercion is specified within an expanded term definition using the @type key.

Listing 4.5: JSON-LD: @type for node and value example

```
1 "@context" : {
2   "@id": "http://example.org/posts#TripToWestVirginia",
3   "@type": "http://schema.org/BlogPosting",
4   "modified":
5   {
6     "@value": "2010-05-29T14:17:39+02:00",
7     "@type": "http://www.w3.org/2001/XMLSchema#dateTime"
8   }
9 }
```

In the listing 4.5, at line 3 we have a node type, while at line 7 we have a value type: the term "modified" is a of type "dateTime" while the node is of type "BlogPosting".
Finally, I would like to explain the concept of *active context*: the @context in a JSON-LD document is not unique, there is the possibility to define more than one, mapping new terms or reusing some already defined. The active context is how the JSON processor handles the presence of multiple context: a list of terms is kept by the processor, updating the IRIs mapped in case of redefinition. So redefining a term overwrites the old "value", keeping active only the last value. Between the two definitions of the same term, obviously, the first value is the one that is active. Each @context in a multiple context definition is called *local context*. Setting a local context to "null" resets the entire active context.

Listing 4.6: JSON-LD: multiple @context example

```
{
  "@context": {
    "name": "http://example.com/person#name ,
    "details": "http://example.com/person#details"
  },
  "name": "Markus Lanthaler",

  "details": {
    "@context":
    {
      "name": "http://example.com/organization#name"
    },
    "name": "Graz University of Technology"
  }
}
```

In the example above 4.6, the term "name" is overridden in the more deeply nested "details" structure. Note that this is rarely a good authoring practice and is typically used when working with legacy applications that depend on a specific structure of the JSON object. If a term is redefined within a context, all previous rules associated with the previous definition are removed.
These explanation of JSON-LD is partial and it covers only the base aspects of it. [**jsonlddraft**] But it is sufficient to cover what I have used in my work.

4.3.4 W3C proposal: pros and cons

The W3C, during the years, has already faced the problem of lack of standards in the highest layer of the structure. So it has published an unofficial draft, from which the idea of the thesis has been taken, discussed and changed in some parts, according to my personal needs and the thoughts, discussed and accepted by the professor [**w3cwot**].
In particular I took from the W3C idea two main things: firstly the idea of a REST service, a "consumable" solution. In particular I found the idea of a "semantic solution", in order to use the full potential of linked data, very innovative and looking to the future. Secondly I shared the "thing description" the W3C proposes: in particular it divides the capabilities of a smart object into three different interaction patterns: *properties*, *actions* and *events*.

- Property: it provides readable and/or writeable data that can be static (e.g., supported mode, rated output voltage, etc.) or dynamic (e.g., current fill level of water, minimum recorded temperature, etc.).
- Action: it targets changes or processes on a thing that take a certain time to complete (i.e., actions cannot be applied instantaneously like property writes). Examples include an LED fade in, moving a robot, brewing a cup of coffee, etc.
- Event: it enables a mechanism to be notified by a thing on a certain condition.

It is fundamental to point out that I am not implementing what they are proposing without making reflections, changes and thoughts to the draft. W3C is nowadays an essential component to standardize protocols and ways of communication on the web, it is composed of web experts having years of experience; it can be considered "somehow" natural that an idea for a thesis comes from someone or somewhat having more influence on the existing technologies than a single student.
Having specified that my work will anyway introduce something new respect to the draft now I am going to list briefly the innovations compared to W3C ideas. Innovations, more generally, are then explained and presented in the following

sections and chapters, without making a schematic comparison continuously, because they are only a part of a bigger and heterogenous work.
Firstly, my idea is provide the developer an indirectly the final user with a description of the whole smart space: a smart space is a very heterogeneous term, it can be outdoor or indoor, composed by different zones or rooms, etc. So my idea is to face all these categories to create interchangeable blocks of my JSON-LD document. In each of these zones, maybe, the same type of device is installed, so the problem to uniquely identify a smart object is obviously one of the fundamental requirements and challenges to face. Also the discovery of devices can be something to care about: the object in the right place is another challenge to be overcome to have a full working system. Secondly, W3C has not specified "how to use" what they are proposing: I decided to put the entire system on local host for some cases and online for others, recommending the developers that will work on the control centers to do the same. Even if there must be some exceptions. The advantages of putting the "smart world" on the web, creating the WoT, have already been explained and presented. The advantage of putting the system on local host is the fact that access is restricted without using any password, it can be useful for example for "public" smart spaces: being in a hotel room I must have access to all the devices in my room but not to others or to the centralized system in the hotel. So a customer can enter the room and control everything without need of authentication. On the other side the owner of the hotel needs to have a complete vision of what is happening in his/her structure: in case of an emergency it is necessary to control everything remotely, assuring that who is using the system has the permissions to do it. This simple case ranges among all the shades the problem can have. Maybe other minor features and changes to the problem are here not listed but the whole work is explained in the next sections.

4.3.5 Syntax of the solution

In this section I am going to define step by step my solution, explaining with listings and images all the elements.
An important and remarkable reflection is needed here: unfortunately it is not possible for me alone to define every kind of smart space and smart objects existing nowadays. I will provide the reader a sample of what I am doing and what is the work. The examples are obviously made to cover all the different shadows of the matter, in order to give a complete idea and a full functional system.

Context Here I would like to explain the keyword @context and its meaning in my work. As said, @context must define the terms are used in the document, so they change for each particular smart space considered. Here I am reporting an example, that could maybe change on the proof of concept

Smartspace

Chapter 5

Proof of Concept

5.1 Non-functional requirements

If the section 3.5, the constraints of the problem can be seen as the functional requirements my development has to have, there is another category of requirements: the non-functional ones, they are important properties that my system must have in order to guarantee full functionalities. They are not specific for the Web of Things but it is important that my system meets them. I am briefly here listing all the non-functional properties:

- *Portability:* to have my application users by the largest number of users possible, but this is not a real requirement in the sense that the application is developed on the web, easy reachable. We are on the border of functional and non-functional requirements.
- *Stability:* system must be always available, and able to offer all its services. For example I should avoid possible system failures during the automatic reload of the configuration in case of a change in the smart space. In addition, data must be durable and not lost for any reasons.
- *Availability:* the services must be always accessible in time. In case of malfunctioning, administrator will provide maintenance in order not to affect service availability.
- *Reliability:* since data are shared among a large number of devices, reliability is essential. Users can base their actions on other users' actions and on devices' status. Moreover, I suppose that the memory where data are stored is stable.
- *Efficiency:* Within software development framework, efficiency means to use as less resources as possible. Thus, system will provide data structures and algorithms aimed to maximize efficiency. I will also try to use well known patterns reusing as many pieces of code as possible, taking care of avoiding any anti-pattern.
- *Extensibility:* My application must provide a design where future updates are possible. It will be developed in a way such that the addition of new

functionalities will not require strong changes to the internal structure and data flow.

- *Maintainability:* Also modifications to code that already exists have to be taken into account. For this reason the code must be easily readable and fully commented.

- *Security:* Using an online service security is always required. The fact that the system will be available only on LANs is a one first step in this direction.

5.2 Package organization

probabilmente diventerà subsection, solo citata qua per non dimenticarla + test cases, cost estimation? (cocomo etc)

Chapter 6

Conclusions and Future Works

Figures Copyright

Chapter 2: State of Art

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Chapter 4: Solution

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Bibliography

[1] Android. *Security-Enhanced Linux in Android*. 2017. URL: `https://source.android.com/security/selinux/` (cit. on p. 9).

[2] André B. Bondi. *Characteristics of scalability and their impact on performance*. WOSP '00, 2000. ISBN: 158113195X (cit. on p. 23).

[3] Inhyok Cha et al. "Trust in M2M communication". In: *IEEE Vehicular Technology Magazine* 4.3 (2009), pp. 69–75 (cit. on p. 22).

[4] Android developer. *Application Fundamentals*. 2017. URL: `https://developer.android.com/guide/components/fundamentals.html` (cit. on pp. 8, 10).

[5] Android developer. *Intents and Intent Filters*. 2017. URL: `https://developer.android.com/guide/components/intents-filters.html#Types` (cit. on p. 7).

[6] Android developer. *Intents and Intent Filters*. 2017. URL: `https://developer.android.com/guide/components/activities/index.htmls` (cit. on p. 8).

[7] Android developer. *Platform Versions*. 2017. URL: `https://developer.android.com/about/dashboards/index.html#Screens` (cit. on p. 4).

[8] N. Elenkov. *Android Security Internals: An In-Depth Guide to Android's Security Architecture*. No Starch Press, 2014. ISBN: 9781593275815. URL: `https://books.google.it/books?id=y11NBQAAQBAJ` (cit. on p. 8).

[9] M. Frans Kaashoek Jerome H. Saltzer. *Principles of Computer System Design*. Morgan Kaufmann, 2009. ISBN: 9780123749574 (cit. on p. 12).

[10] Greg Kroah-Hartman. *Linux Kernel in a Nutshell*. O'Reilly Media, 2006, p. 3 (cit. on p. 6).

[11] Leslie Lamport. "Time, Clocks, and the Ordering of Events in a Distributed System". In: (1978) (cit. on p. 23).

[12] Verge Staff. *Android: A visual history*. 2011. URL: `http://www.theverge.com/2011/12/7/2585779/android-history` (cit. on p. 3).

[13] A.S. Tanenbaum and M. Van Steen. *Distributed Systems Principles And Paradigms 2Nd Ed.* Prentice-Hall Of India Pvt. Limited, 2010. ISBN: 9788120334984. URL: `https://books.google.it/books?id=Fs4YrgEACAAJ` (cit. on pp. 10, 16, 17).

[14] Lars Vogel. *Android development with Android Studio - Tutorial*. 2016. URL: `http://www.vogella.com/tutorials/Android/article.html` (visited on 06/20/2016) (cit. on pp. 5, 6).