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Ubiquitous indoor wireless geo-location system

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The becoming of this dissertation compels for a great commitment from the author, but also from all of those who one way or another helped him in accomplishing this work. In this journey, many were those who many made it possible to reach the end.

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Thank you.

Abstract

Positioning systems are an established need in the current world. The ability to identify the position of a given object in a given context is a common service in our fast-paced, online and always-connected global community. For normal day-to-day usage outdoor systems have a matured and integrated usage, from destination guidance to social media applications status updates, all can use the current positioning systems to enhance its services. For inside systems the same does not happen, there is a clear gap in the applicability and usage of positioning systems for indoor locations.

This thesis aims to address that gap, that opportunity and discusses an ubiquitous Indoor Positioning systems (IPS) solution by studying the technologies, systems, techniques and algorithms used for in current locations systems. It proposes and implements a platform for indoor positioning that locates clients using a mix of techniques which is called Nearest Neighbours and Trilateration with pre-mapped points (NNTP) in order to offer the easiest implementation and extensibility in new environments and offers a strongly orientated for services platform .

Keywords

geolocation; wireless; positioning; ubiquity; indoor location

Resumo

Nos dias de hoje sistemas de posicionamento e localização são um serviço estabelecido e maduro. A habilidade de identificar a posição de um objecto dado o contexto local é um serviço comum na nossa sempre-ligada aldeia virtual. Para o uso diário apenas os sistemas ao ar livre tem a maturidade e estão integrados o suficiente para este tipo de utilização, desde guias GPS até actualização de estados em aplicações moveis, todos estes podem beneficiar dos actuais sistemas de posicionamento. Para sistemas que funcionem dentro de edifícios o mesmo não acontece, existe uma clara falha na aplicabilidade e utilização de sistemas de posicionamento dentro de edifícios.

O objectivo desta tese é de responder a essa falha, a essa oportunidade e discutir um sistema de posicionamento dentro de edifício, estudando as tecnologias, sistemas, técnicas e algoritmos actualmente usados. A tese propõe e implementa uma plataforma para posicionamento que localiza os clientes usando uma mistura de técnicas que se chamou de NNTP para oferecer a maior facilidade em implementação e extensibilidade para um novo ambiente, oferecendo uma plataforma fortemente orientada para serviços ubíquos.

Palavras Chave

geolocalização; wireless; posicionamento; ubiquidade; localização

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ACRONYMS

AGPS Assisted Global Positioning System

AoA Angle of Arrival

AP Access Point

BT Bluetooth

CN Cellular Network

Co-Sim Co-Similarity

DOLPHIN Distributed Object Locating System for Physical space Inter networking

DSSS Direct-sequence spread spectrum

GLS Geo-Location Systems

GPS Global Positioning System

HTTP Hypertext Transfer Protocol

IPS Indoor Positioning systems

IR InfraRed

IST-TP Instituto Superior Técnico - Taguspark

JSON JavaScript Object Notation

LOS Line-of-Sight

MAC Media Access Control

NLOS Non Line-of-Sight

NNTP Nearest Neighbours and Trilateration with pre-mapped points

NN Nearest Neighbour

OFDM Orthogonal frequency-division multiplexing

OPS Outdoor Positioning Systems

RFID Radio-Frequency IDentification

RF Radio-Frequence

RSSI Received Signal Strength Indicator

RSS Received Signal Strength

RToF Roundtrip time-of-flight

RTT Round-trip time

SS Signal Strength

TBC To be calculated

TDoA Time Difference Of Arrival

ToA Time Of Arrival

US Ultra-Sound

UWB UltraWide-Band

WLAN Wireless Local Area Network

WLAN Wireless Local Area Network

WPAN Wireless Personal Area Network

1

Introduction

Contents

Geolocation: *The process or technique of identifying the geographical location of a person or device by means of digital information*.
Positioning systems are an established need in the current world. The ability to identify the position of a given object in a given context is a requirement for our fast-paced, online and always-connected global community.
Indoor Positioning systems (IPS) for normal day-to-day usage still need maturing. Targeting objects position inside a building is still fallible mainly because of the lack of Line-of-Sight (LOS) and also because the current widely spread wireless technologies do not strive for indoor location. In contrast, Outdoor Positioning Systems (OPS) exist with a well matured technology platforms and techniques such as Global Positioning System (GPS), and their current evolution is towards the enhancement of the positioning process itself, with the help of hybrid techniques or systems since its usage is well integrated in our lifes.

This thesis discusses an ubiquitous IPS solution by studying the technologies, systems, techniques and algorithms used in current locations systems. It proposes and implements a platform for indoor positioning, locates clients using a mix of algorithms namely Nearest Neighbours and Trilateration with pre-mapped points (NNTP) in order to offer the easiest implementation and extensibility in new environments. Technological-wise the platform is strongly orientated for servicing in a ubiquitous fashion by having a great modularity emphasis and ease of requirements from the communications and interventionists(users, systems, infrastructures) view point.

Reinforcing the need for a solution of this kind, during this thesis development Google announced it was working on Google Indoor Maps, having it launched earlier this year.

1.1 Motivation

Nowadays the widespread usage of mobile devices has made geolocation services a standard requirement. The usefulness of knowing the location has been integrated in mobile applications in various ways, from the most common where-is-the-place to the geolocation variable when searching for terms in the internet or just when using applications that interact differently depending on the user location. Google is able to answer different answers when searching for portraits if the user is near a museum or shopping malls.

Outdoor location tracking is a very mature technology while indoor location systems still lack the precision, availability and ease of usage. The challenge of this thesis is to provide a indoor locations service built on a platform that is easily integrated, can accommodate new services and be accessed in a easy transparent and always available.

1.2 Objectives

The main objectives for this thesis is to provide an ubiquitous indoor location platform used for identifying the users position. The platform should be built in the current standarts of information technology engineering for usage and integration, be accessible an easily extensible for future services. Being designed at the Instituto Superior Técnico - Taguspark (IST-TP) facilitys, the main objectives for the service is to provide location, with an acceptable margin of error, and guidance for a user in order to allow them to easily reach its destination inside the campus.

The most crucial objective is the **positioning determination**, it is independent from the remaining the features and is the key feature required in any positioning system. The position determination feature is the process on which the solution receives the input information from a user and calculates his position. One of the key aspects that differentiate positioning from location is the relevance to the user, and as such, the **position visualisation** is an objective that will render the calculated position into a meaningful information by visually showing the user where he is. In order to help a user reach a desired room, the **orientation guide** will allow for a meaningful orientation leading the user from its current position to the desired location.

The solution should be able to be used ubiquitously, have a low cost and high value concerning its implementability and should be prepared for be extensible when required. This renders 3 objectives: The **ubiquity** defined as a property that allows for a greater interaction from multiple user-platforms, widening the range of usability and users; The **extensibility** feature that directly relates to the solution life-cycle, since features tendentiously grow, the implementation of new ones should be easily added/changed; And an important requirement when analysing the cost-value of any solution, the **implementability** is an important objective that determines the viability of a solution for given problem.

1.3 Definition of requirements

In order to achieve the objectives, it is required to have a fully 802.11 covered inside building in order to maintain a continuous precisive positioning and access to the proposed platform. This ensures that a mobile client is able to send the its environment informations to the platform which renders the calculations and displays/allows for interaction with the client.

The solution is required to determine the user location to a room-wise precision and to provide guidance/orientation inside the building. For the solution to determine the user's location a necessary basic positioning data is required. This data is the necessary survey information of the area where the solution is implemented and it is used to calculate the clients position. In order to provide guidance to the user, the information of the users geo-magnetic orientation is required and allows to calculate the correct orientation which the client should follow to reach its desired location.

1.4 Dissertation outline

This dissertation is composed of 6 Chapters.

Chapter 2 presents the current technologies, techniques and algorithms in geolocation services described in the state of art. In the third chapter, the proposed solution is presented detailing the proposed platform and location process algorithms based on the needed features and requirements. In Chapter 4 the implementation of the proposed platform and a wireless environmental study in the IST-TP campus is presented. The fifth chapter describes the evaluation and analysis to the implemented platform and its services. The sixth and final chapter concludes the overall of this dissertation.

2

State of the art

Contents

In this chapter it is described the research and analysis of the most significant technologies and systems for Geo-Location Systems (GLS). Existing state of art represents the starting point to a larger understanding of what is currently available and used in this area. This presentation is divided in three parts; the first, presents an overview of the major Geo-Location Systems types such as GPS or Cellular-Based Location and an evaluative-comparison, the second part focuses on the techniques for radio based positioning location, and the last part discusses the key algorithms used in location processment.

2.1 Geo-Location Systems

"*Geolocation is closely related to positioning but can be distinguished from it by a greater emphasis on determining a meaningful location(e.g. a street address) rather than just a set of geographic coordinates.*"[1]

Currently, a great number of services and systems use GLS to achieve their goal. In order to better understand those GLS, it is crucial to separate them, in this case through technological-base, system and/or technique, to better understand their characteristics.

The following section is structured with emphasis on the technology and for each, the commonly deployed system. From the most used GPS to the less known Ultra-Sound (US), their capabilitys are summarized in a comparison table at the end of the section. This division allows for a more broad explanation of each technology and supporting GLS.

2.1.1 Global Positioning System Technology

The GPS is a space-based satellite navigation system that provides location and time information in all weather, anywhere on or near the Earth, where there is an unobstructed line of sight to four or more GPS satellites [2].

In 1957, the two American physicists, William Guier and George Weiffenbach, decided to monitor the recently launched Sputnik's radio transmissions; based on the Doppler Effect, Figure 2.1, they could pinpoint the satellite position, a prove-of-concept which later in 1994, became a (almost-) world-wide and fully operational navigation system.

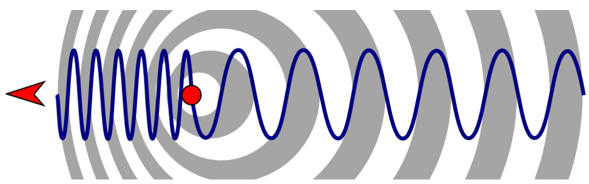

Figure 2.1: Change of wavelength caused by motion of the source.

GPS satellites transmit two radio signals. These are designated as L1 and L2. Common GPS use L1 signal frequency (1575.42 MHz) in the UHF band. The signals travel by line of sight, meaning they will pass through clouds, glass, plastic, etc, but will not travel through solid objects such as buildings and mountains.
The GPS signal contains three different bits of information: a pseudo random code that identifies which satellite is transmitting information; an almanac data that describes the orbital courses of the satellites; and ephemeris data that tells the GPS receiver where each GPS satellite should be at any time throughout the day. Using these informations a GPS device pinpoints its own location in reference with the above satellites.

Not considering the military applications and the different nations similar systems as Galileo (European), Glonass (Russian) or Compass (Chinese), GPS is the most common GLS, offering “significant benefits to surveyors, mappers and construction workers, as well as other civilian users of the system, including aviation, marine and automobile navigation, agriculture and asset management. As a result of the modernisation program, meter-level absolute positioning accuracies may be achieved in real-time..”[3].

The combination of different technologies in this system is consolidating it. Assisted Global Positioning System (AGPS) “provides a natural fit for hybrid solutions because it uses the wireless network to supply assistance data to GPS receivers..” [2].
The assistance methods are distinguishable in two types: one speeds up the satellite acquisition process, Mobile Station Bases supply the orbital data (the almanac) or the precise time; and the other improves position calculation by using Mobile Station Assistance that surveys a calculation of the snapshot of the GPS signal at specific times.
Although augmenting GPS capability and making the system more robust, such as predicting Time Of Arrival (ToA) at the mobile receiver, AGPS as GPS still require a line of sight to the satellites, rendering then unusable in indoor environments.

Given the requirements, the GPS offers little in the strict technological sense since the usage is limited to an outdoor with Line-of-Sight (LOS) area. Even taking this fact into account, it is a good example of a GLS, mainly because of it is reliability; thought most mobile devices have special GPS components, its ubiquity makes GPS a standard in almost all mobile platforms nowadays.

2.1.2 Ultra-Sound

“Ultrasound signals are used by bats to navigate in the night, which inspire people to design a similar navigating system in the last hundreds of years..”[4]

Following the bats analogy, an ultrasonic pulse is generated in a particular direction. If there is an object in the path of this pulse, part or all of the pulse will be reflected back to the transmitter as an echo and can be detected through the receiver path. Thus indicating the obstacle, and by using ToA techniques, it is possible to determine the distance, as shown in Fig.2.2.

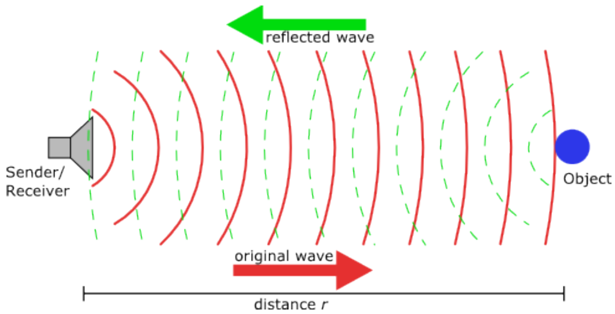

Figure 2.2: Principle of an active sonar

Either indoor or outdoor, the system works by having one or several emitters and one or several receivers which relates to cost/effectiveness in deployment. Ultra-Sound (US) is known to be better than InfraRed (IR) in cost/efficiency, resistance to interference and scalability, although IR have better accuracy (several millimetres against several centimetres)[4], the applicability of US technology is considerably larger in the GLS field.

This technology requires a emitter and a receiver, Active Bats[5] developed by AT&T Cambridge and Crickets[6] by MIT Laboratories switch these stances to locate an object, being the second more accurate and scalable [7]. While both must rely on these roles, the Distributed Object Locating System for Physical space Inter networking (DOLPHIN)[8] targets a more ubiquitous system using distributed positioning algorithm on each nodes, making each element an emitter and a receiver at the same time.

Ultra-Sound (US) systems offer a great accuracy in a large indoor space; but as commonly seen, this is a specific technology which is not usual nor used in typical infrastructures. This requires a great consideration in the cost of implementing it into existing platforms.

2.1.3 Ultra-WideBand

Multi-path distortion of radio signals or even full reflection by walls in indoor environments is an inherent problem in Radio-Frequence (RF) systems, a problem which UltraWide-Band (UWB)[9] solves, to some extent.

By having pulses of a short duration (less than 1 ns) UWB GLS makes it possible to filter the reflected signals from the original signal, which naturally offers greater accuracy. As seen in Figure 2.3, the modulation is done in small bursts and spread in the band, this offers greater chance for the signal to pass different types of objects without interference.

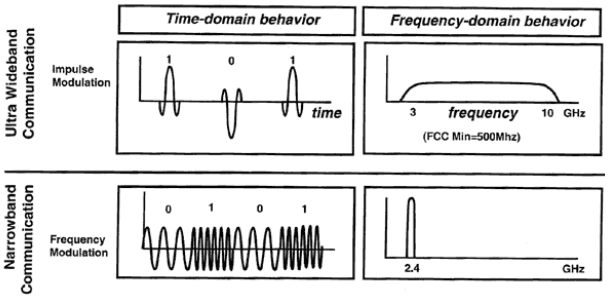

Figure 2.3: UltraWide vs Narrow Band Communications

This technology is enhanced by taking advantage of both the Time Difference Of Arrival (TDoA) and Angle of Arrival (AoA) techniques, providing a flexible capability of location sensing. Since it measures signal angles and difference in arrival times, complex indoor environments including walls and doors do not significantly influence the performance[9].

Currently UWB technology deployment is not massified, since it is not able able to be easily deployed/integrated on legacy/existing systems; in addition UWB is not very well standardized as seen further ahead.

One implementation of a GLS using UWB is Ubisense[10].The Ubisense system consists of three parts: the sensors, the tracked tags and the Ubisense software platform. The sensors, which are fixed in known locations, receive the UWB signals from the tracked tags. Then the location data of the tags is forwarded from these sensors via existing Ethernet to the Ubisense software platform, which analyses and displays the location of the tags.

Although strategized to be implemented in PC peripherals and mobile devices due to it is low power emissions and advantages in indoor environments; the slow progress in UWB standards development; the cost of initial implementation; it presents several reasons for the limited use of UWB in consumer products (which caused several UWB vendors to cease operations in 2008 and 2009)[11], raising the implementation cost for a GLS with this technology.

In a statement from the IEEE 802.15.3a task force leader, the uncertainty of UWB standards is clear: *'This was not a factor in this decision but from a standards perspective it probably was and is too early to write a UWB standard given the regulatory and market uncertainty in the world market'*[12].

Given that the current state-of-art is not mature, nor deployed enough to build an easily deployable and usable Indoor Positioning systems (IPS) around it, these systems will not be considered as a viable solution.

2.1.4 Cellular Network

'Wireless is freedom. It is about being unleashed from the telephone cord and having the ability to be virtually anywhere when you want to be. That freedom is what cellular is all about.'[13]
-Martin Cooper, the Motorola team leader for the first mobile phone.

'Recently' the technology behind mobile wireless communications has evolved from the '0G' Mobile Telephone Service Push-to-Talk to the '4G' native-IP network. This late part of mobile wireless telecommunications has a core system of Cellular Network (CN), a network supported by a multitude of Base-Stations, distributed over land areas, in order to cover and sustain the communication with the wireless mobile devices.

In a cellular radio system, the ground to be covered with radio service is divided into regular shaped cells; using the transmission power as a delimiter, it enables for a mobile device to change the cell in use. Each of these cells is assigned multiple frequencies which have corresponding radio base stations as depicted below, in Figure 2.4. This proximity rules the usage of frequencies between neighbour base stations, in order to avoid co-channel interference.

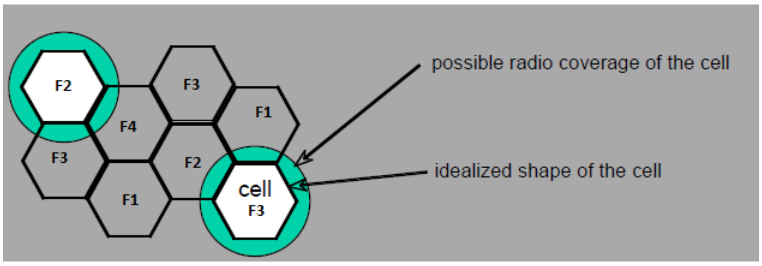

Figure 2.4: Example of frequency reuse factor in a cellular network

86% of the world population uses a mobile phone[14]. This number illustrates the penetration of mobile technology in the world and consequently the relevancy of GLS based on this technology. Being one of the most in-use technology on this study, and having many GLS that use this technology with different techniques, it is important to enumerate the main techniques to achieve geo-location, such as:

Cell-ID The Cell Identification (Cell-ID) or Cell Of Origin (COO) method. This method relies on the fact that mobile cellular networks can identify the approximate position of a mobile handset by knowing which cell site the device is using at a given time. The main benefit of Cell-ID is that it is already in use today and can be supported by all mobile handset[15].

Smart antennas techniques Smart-antenna-based location systems use the Angle Of Arrival (AOA) as the measurement parameter. The AOA signals at the base station are determined by electronically steering the main lobe of an adaptive phased array antenna in the direction of the arriving mobile signal. The system can automatically adjust the antennas beam pattern, frequency response, and other parameters to enhance location performance. The position of an MS is calculated from the intersection of a minimum of two lines of bearing using smart antennas techniques.[16]

Fingerprinting Similar to A-GPS, this system uses the radios signals, such as 802.11 Wireless Beacons, Cell-ID, and corresponding multipathed signals around the MS, computes a position and stores it in a database for future assist in the geo-location of the device.

Although this technology represent a good GLS considering the reliability, deployment and ubiquity aspects, there is a major problem which is the difficulty to track a position for indoor. This difficulty is due to the need of several base stations overlapping same area with low signal interference, and because of the cost of each base station, this is not a good technology taking into account the proposed requirements.

2.1.5 Radio-Frequency Identification

On August 4, 1945, a delegation from the Young Pioneer organization of the Soviet Union presented a sculpture to the U.S. Ambassador Averell Harriman, as a ‘gesture of friendship’ to the USSR’s World War II ally [17]. Inside this gift there was an espionage tool invented by Léon Theremin for the Soviet Union, which retransmitted incident radio waves with audio information. Sound waves vibrated a diaphragm, which slightly altered the shape of the resonator, which modulated the reflected radio frequency. Even though this was a covert listening device, not an identification tag, it is considered to be a predecessor of Radio-Frequency IDentification (RFID) technology, because it was likewise passive, being energized and activated by waves from an outside source [18].

As shown in Figure 2.5, in every RFID system the transponder Tags contain information. This information can be as little as a single binary bit, or a large array of bits representing any type of information that can be stored in digital binary format.

An RFID system has several basic components, including a number of RFID readers, RFID tags, and the communication between them. The RFID reader is able to read the data emitted from RFID tags. RFID readers and tags use a defined RF and protocol to transmit and receive data. RFID tags are categorized as either passive or active[15].

Wireless and non-line-of-site characteristics are the advantages of this technology. They can

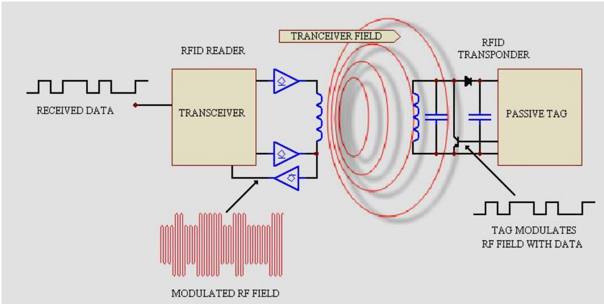

Figure 2.5: A typical RFID system

work in high speeds; their RF tags can be read in any environment and are also very cost effective. On the down side, the typical reading range is 1–2 meters in passive RFID tags and up to tens of meters in active RFID tags combining the cost of the readers which is relatively high [15] and the technology is not found on most mobile devices.

Passive RFID tags operate without a battery. They are mainly used to replace the traditional bar code technology and are much lighter, smaller in volume, and less expensive than active tags. They reflect the RF signal transmitted to them from a reader and add information by modulating the reflected signal. However, their ranges are very limited providing a low-range GLS.

Active RFID tags are small transceivers, which can actively transmit their ID (or other additional data) in reply to an interrogation. Frequency ranges used are similar to the passive RFID case except the low-frequency and high-frequency ranges. The advantages of active RFID are with the smaller antennae[15] and in the much longer range can provide a better GLS, sustaining a cost upgrade.

A well-known GLS using the RFID technology is SpotON [19]. SpotON uses an aggregation algorithm for 3-D location sensing based on radio signal strength analysis. In the SpotON approach, objects are located by homogeneous sensor nodes without central control, i.e., Ad Hoc manner. SpotON tags use the Received Signal Strength (RSS) value sensor measurement for estimating inter-tag distance. They exploit the density of tags and correlation of multiple measurements to improve both accuracy and precision. Another well-known GLS is called LANDMARC (indoor location sensing using active RFID)[20]. In order to increase accuracy without placing more readers, the system employs the idea of having extra fixed location reference tags to help location calibration. These reference tags serve as reference points in the system. The LANDMARC approach requires RSS from each tag to readers.

Considering an indoor area and as an GLS it is commonly used in commercial solutions, notably Wallmart is a known case-study of the usage of RFID benefiting from a 200% profit revenue in 2004[21]. Regarding a Indoor Positioning systems (IPS), as stated above, there are few home/business standard technologies that aggregate RFID in its standards, narrowing down its availability in which to deploy an IPS.

2.1.6 Wireless LAN (IEEE 802.11)

'IDC's Worldwide Quarterly Wireless LAN Tracker® reports the combined consumer and enterprise worldwide WLAN market segments annual growth of 20% for the 7th year in a row '[22] - International Data Corporation, global provider of market intelligence, for the consumer technology telecommunications.

Wireless Local Area Network (WLAN) consists of the linkage between two or more devices using some wireless distribution method (typically spread-spectrum or OFDM radio) as shown in Figure 2.6. This gives users the mobility to move around within a local coverage area and still be connected to the network. The majority of WLANs are based on IEEE 802.11 standards, marketed under the Wi-Fi brand name, originally for IEEE 802.11b [23].

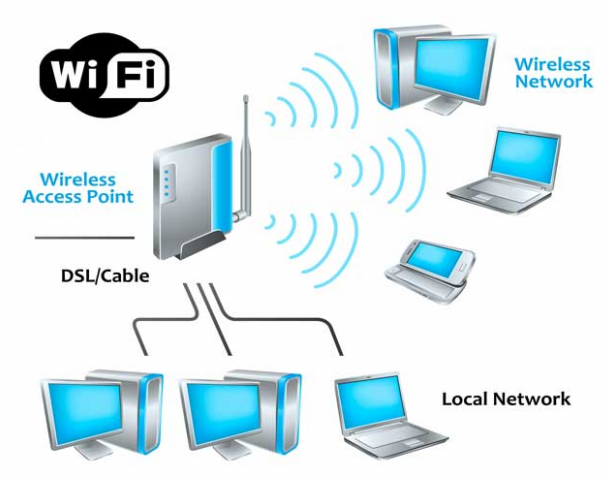

Figure 2.6: A typical WLAN representation

One of the worldwide most deployed technology for wireless access [24], WLAN was obviously not designed and deployed for the purpose of positioning. However, measurements from the Signal Strength (SS) of the signal transmitted by either Access Point (AP) or station, can result in the location of a mobile user [25].

Many SS based techniques have been proposed for position estimation in environments in which WLAN is deployed. There are essentially two categories of such techniques. One uses a signal propagation model and information about the geometry of the building to convert SS to a distance measurement. With knowledge of the coordinates of the WLAN APs, the method of trilateration/multilateration can then be used to compute the position of the mobile user. The other category of WLAN positioning is known as location fingerprinting. Both explained further ahead in greater detail.

One system for position location using WLAN is RADAR[25]. RADAR system records and processes the signal strength information received from base stations. These stations are positioned to provide overlapping coverage of the area of interest. It uses signal propagation modelling to estimate the object location. Signal strength information collected at multiple receiver locations are triangulated to find the user coordinates.

Using a different approach the COMPASS[4] system requires a pre-mapped location-space and uses fingerprinting location technique with a probabilistic positioning algorithm to determine the location of a user.

This technology gathers two key features for an indoor GLS: it is widely deployed, a standard in every home/business infrastructure; and the platforms that support it (for the most cases AP and mobile devices) are mature enough to offer high customizability. It also has two main disadvantages: it is very sensible to bodys of water or metallic surfaces which distort or stop the signal propagation and the power measurement in standard devices is a non normed 8-bit level flag [15].

2.1.7 Bluetooth (IEEE 802.15)

Inspired by the tenth-century king Harald I of Denmark, Bluetooth (BT) was the name given by Jim Kardach. While the king united dissonant Danish tribes, Jim Kardach strided to do the same with wireless computer and mobile devices communications protocols[26].

Ratified in IEEE 802.15 standard, BT is a specification for Wireless Personal Area Network (WPAN). Bluetooth enables a range of 100 m (Bluetooth 2.0 Standards) in Class 1, but typically used in Class 2 (10 meter) or Class 3 (1 meter) communications on mobile devices[4]. Piconets are formed under Bluetooth specifications by using a master/slave based MAC protocol. Bluetooth technology has been embedded in various types of mobile and stationary devices. In addition, Bluetooth chipsets are low cost, which results in low price tracked tags used in the positioning systems.

As a GLS in Bluetooth-based positioning systems [27],[4],[28], various Bluetooth clusters are formed as infrastructures for positioning. The position of a Bluetooth mobile device is located by the effort of other mobile terminals in the same cluster. In this manner, a Bluetooth-based IPS is introduced.

One of the implementations of a GLS with BT is the Topaz local positioning solution. This modular positioning solution is made up of three types of elements: positioning server(s), wire-

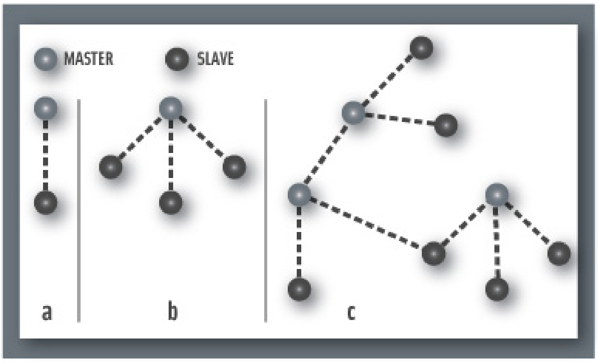

Figure 2.7: Bluetooth Master-Slave relation in a piconet

less access points, and wireless tags. This system provides room-wise accuracy (2-m spatial accuracy), with positioning delay of 15 to 30 s[4]. The system is commonly deployed integrating infrared technology with the Bluetooth positioning and communication capabilities.

Having good properties for an indoor GLS, this technology has a high latency, and its reliant of density of tags in an area to position a device increasing the costs for an IPS system. Since the range of the signal is in the 10-15m range[15], the coverage of an entire building will require a high amount of tags and subsequently will increase the cost of the solution.

2.1.8 Geo-Location System Types : Analysis and conclusion

In order to properly evaluate the presented Geo-location System, this section presents a comparison, in Table 2.1. This comparison consideres this technologies, addressing the most important aspects, namely:

Accuracy the most important requirement of positioning systems. Typically, the mean distance error is adopted as the performance metric, which is the average of the Euclidean distance between the estimated location and the true location.

Precision considers the mean distance errors from the calculated to the true position. However, location precision considers how consistently the system works, i.e., it is a measure of the robustness of the positioning technique as it reveals the variation in its performance over many trials.

Techniques although many implementations of techniques can be used for various technologies, the most important ones are described. For each technology, typically, it exists one or two core techniques that enable the location service.

Cost the cost of a positioning system depends on several factors. The most reliant ones include money, time, space, weight, and energy. The time factor is related to installation and maintenance. Mobile units may have tight space and weight constraints. Measuring unit density is considered to be a space cost.

Availability the usage of a technology is bound to the deployment and easy of acquisition or utilization for this technology.

	GPS	Ultra-Sound	UWB	Cellular N.	RFID	WLAN	BT
Accuracy	5-10m[15]	2-15cm[29]	15cm[29]	10m[15]	1-2m[15]	3-5m[15]	2m[15]
Precision	95%[3]	50%[29]	99%[29]	80%[15]	50%[15]	50%[15]	95%[15]
Techiques	TDoA	RTOF	TDoA+ToA	RSS	RSS	RSS	RSS
Cost	High	Medium-High	High	High	Low-Medium	Very-Low	Very-Low
Availability	High	Low	Low	High	Low	Very-High	Medium

Table 2.1: A comparison chart of the state of the art technologies

As seen on Table 2.1, several technologies can be eliminated such as GPS and CN given their need of LOS, US, and UWB, could be promising, however the low usage, and high cost are not suitable. In RFID and BT, the infrastructural need for the first, and the density of devices needed by the second, make these systems less suitable as well. Resulting in WLAN the most suited technology, given its high availability, low cost, and a considerable accuracy for an IPS.

2.2 Radio Based Location Techniques

After introducing the commonly used technologies in Geo-Location Systems (GLS), this section discusses the main techniques for the location using those base technologies. Focusing only on Radio signals, these Location Techniques are the principal concepts, measurements and procedures that allow for the location process to pinpoint the positioning.

Figure 2.8 depicts the division for these techniques. The Radio Beacon represents the broadcasted signal beacons retrieved in the locating point, Time-based techniques are relative to signal delay, Angle techniques concern the angle of arrival of the signal, and Signal strength which is the information of signal beacons strength around the locating point. The following describes the 4 main techniques.

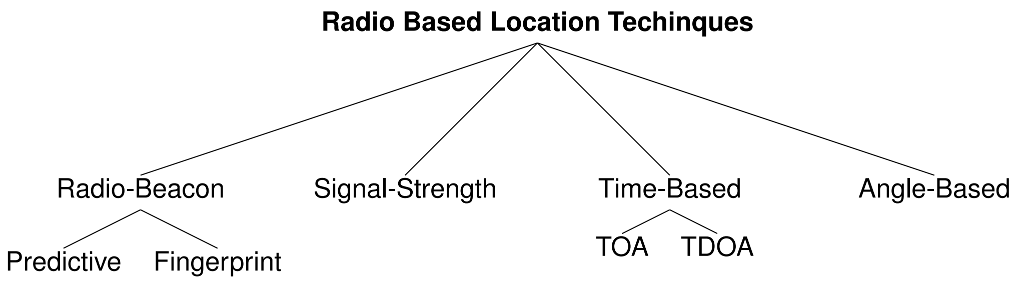

Figure 2.8: A division in radio based location techniques

2.2.1 Radio Beacon

One class of location techniques, which typically is referred as beacon-based location systems, estimates the position of a device by referencing nearby radio sources. Although versatile, creating the necessary map of the radio sources, can be a costly and a time-consuming process [30].

Beacon-based systems typically use signals from 802.11 Access Point (AP), but Bluetooth devices, GSM cell towers, FM radio transmitters and combinations of these can also been used [31] as a measurement. Beacon-based systems have two advantages over other types of location systems. First, the larger number of fixed radio sources in the environment provides high coverage [30]. Second, because beacon-based systems use standard radios built into the user's device, there is no need for hardware. A drawback of beacon-based systems that estimate a device's absolute location, is that they require a map of nearby radio sources to interpret the radio-scan results.

In radio beacon signals, position estimation is accomplished by either with predictive radio models or with radio fingerprinting, currently both of these models use Signal Strength (SS) to better correlate the position of the mobile device. Predictive radio models usually take into account antenna types and their characteristics, and environment conditions. There are some predictive radio models like '*war driving*' [31] that use these data to estimate a user's position[32]. In radio fingerprinting approach, a radiomap with site survey is created.

2.2.1.A Predictive Radio Model

The standard approach to a Predictive Radio Beacon Model, demands a pre-deployment mapping and uses supervised learning techniques. By creating several sets of data using vectors of signal strengths, one for each of a collection of known locations, matching them against the physical distance measurements with respect to a reference object such as a wall, the model building phase produces the basic map.
In the online phase, a wireless terminal is located by matching the terminal's RSS measurements against the model. Researchers have applied many supervised learning methods to this problem including nearest neighbour methods, model electromagnetic propagation, support vector machines, and assorted probabilistic techniques.

One example is Active Campus[33] a beacon-based system that use a predictive radio model to estimate location. Radio models range from simple heuristics (e.g,. 802.11 can be heard for 100 meters in all directions from the access point) to complex ones that consider antenna types and the attenuation of various building materials. The radio map in these systems contains the position of each known radio beacon as well as other possibly useful characteristics (e.g., antenna height or transmit-strength).

Gathering extensive training data and the required physical measures of location ("profiling") involves a steep upfront cost and deployment effort. Furthermore, even in normal office environments, changing environmental, building, and occupancy conditions can affect signal propagation and require repeated data gathering to maintain predictive accuracy.

2.2.1.B Radio Fingerprinting

Fingerprinting-based location systems are powerful and simple. In a fingerprinting system, the radio map takes the form of radio-scans tagged with the location where the scans were performed. When a device wants to estimate its location, it performs a scan, finds the radio scan in the map that it most closely matches, and estimates the device to be located where that matching scan was taken.

The match between fingerprinting and self-mapping is not as clear as for predictive systems.

While high coverage can likely be obtained, accuracy may degrade, undermining the key advantage of fingerprinting[32].

A system using fingerprinting is Assisted Global Positioning System (AGPS), although effective, its uses fingerprinting to narrow down the GPS satellites on wich to lock they signal; alone is poorly suitable for and IPS, because its of the accuracy being dependent on the density and visibility of surrounding AP (or signal emitters) [31].

Hybrid techniques of Fingerprinting and SS are considered a better solution (and largely deployed), providing the fast modelling of an area while achieving better accuracy with the SS techniques.

2.2.2 Time-based

Time-based positioning techniques rely on measurements of travel times of signals between nodes. If two nodes have a common clock, the node receiving the signal can determine the Time Of Arrival (ToA) of the incoming signal that is time-stamped by the reference node [9].

This concept requires precise time synchronization of all involved fixed and mobile units. In this case, the absolute time synchronization must have at least a precision related to the desired positioning accuracy. For example, a positioning accuracy in the decimetre range requires an absolute time synchronization significantly below 1 ns.

Most common today are the Time Of Arrival (ToA) and Time Difference Of Arrival (TDoA), although Roundtrip time-of-flight (RToF) is a known technique, the imposed requirement of almost absolute clock synchronization shows that this requirement is difficult to meet. Provided a system with a fairly good crystal clock source with 25 ppm accuracy, a processing time of 1 ms in Roundtrip time-of-flight (RToF), the system delay to response can still lead to a measurement deviation of several meters [9].

Although many others use this techniques, GPS is a good example of this concept because, the distance to the satellites are enough to bear the technological computing delay. Taking into account 802.11 technology, the distances of devices, nor do the common devices clock speed suffice, equation 2.1:

$$t_s = d \div c \tag{2.1}$$

Being $\mathbf{t_s}$ the time for a electromagnetic wave to travel the distance **d** at the speed of light **c**, it takes for a common indoor distance of 10 meters, 30 ns for the signal to travel. Requiring a processing source of a significant faster time than the currently available in 802.11 devices.

2.2.2.A Time Of Arrival

Time Of Arrival (ToA) method measures the Round-trip time (RTT) of a signal. Half of the RTT corresponds to the distance of the mobile device from the stationary device as shown in Figure 2.9. Once the distances from a mobile device to three stationary devices are estimated, the position of the mobile device with respect to the stationary devices can easily be determined using the intersecting circles of trilateration [34].

ToA requires accurate and tightly synchronized clocks since 1.0 us error corresponds to a 300 m error in the distance estimation [34]. Thus inaccuracy in measuring time differences should not exceed tens of nanoseconds since the error is propagated to the distance estimate[35].

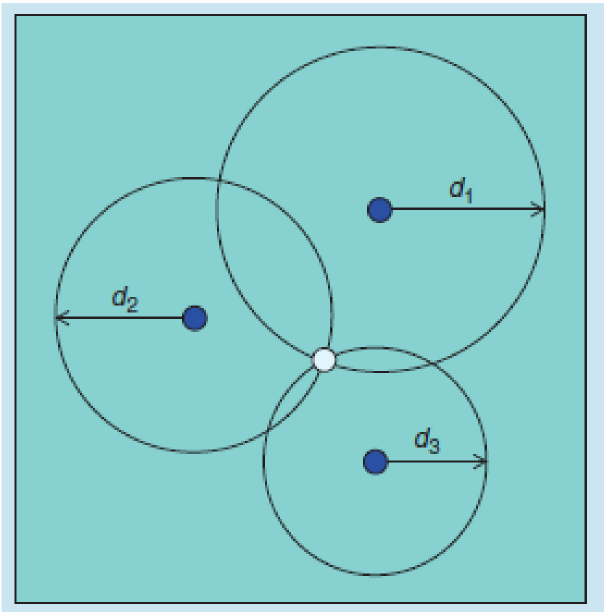

Figure 2.9: Distance-based positioning technique.

Because of clock synchronization, and the electromagnetical wave propagation properties, this kind of technique can be used on RF signal with GPS (because the distance satellite-device is large enough) and in UltraSound systems [7].

2.2.2.B Time Difference Of Arrival

Time Difference of Arrival (TDOA) method is similar to Time of Arrival using the time difference of arrival times as shown in Figure 2.10. However, the synchronization requirement is eliminated though high accuracy is still an important factor. As in the previous method, inaccuracy in measuring time differences should not exceed tens of nanoseconds.

Most of the available solutions today are remote TDoA systems. In TDoA systems, the time-difference of arrival of the signals received in several pairs of measuring units is evaluated. The benefit of TDOA systems is that it is only necessary to synchronize the measuring units. This

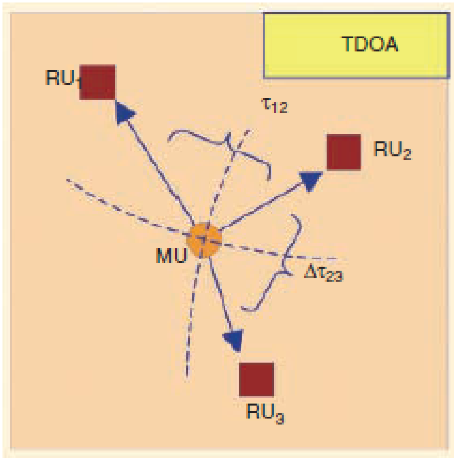

Figure 2.10: TDOA, where is measured the propagation time difference from two travelling signals and the position is given by the intersection of hyperbola with foci at the RUs.

synchronization is done using a backbone network or a reference transponder in a known position [36].

In order to increase the accuracy of a IPS, TDoA can be used with Direct-sequence spread spectrum (DSSS) or Orthogonal frequency-division multiplexing (OFDM) WLAN by Li, et al. [37] but with few promising results at a room scale.

2.2.3 Angle-Based

Angle of Arrival (AOA) refers to the method that the position of a mobile device is determined by the direction of the incoming signals from other transmitters whose locations are known.

Figure 2.11: A simple illustration of the Angle of Arrival technique.

Triangulation technique is used to compute the location of the measured mobile device. However, a special antenna array is required to measure the angle, and has a low applicability in Non Line-of-Sight (NLOS) systems due to multipath distortions.

2.2.4 Signal strength

The default MAC protocol operation in IEEE 802.11 is based on a carrier sense multiple access with collision avoidance (CSMA/CA). To implement this protocol the physical layer measures the RF energy at the antennae and determines the strength of the received signal. The IEEE

802.11 standard specifies the Received Signal Strength Indicator (RSSI) that is the measure of the Radio-Frequence (RF) energy received by the radio. RSSI up to 8 bits (256 levels) are supported, but the absolute accuracy is not specified [38].

As Signal Strength (SS) is not a technique in itself, it is a basis that allows for multiple techniques to exploit and render position information. The most know method is trilateration, but as seen above, from fingerprinting to TDoA, many techniques benefit from the mixed usage of SS.

The trilateration method uses the distance between a AP and the mobile device. It requires a minimum of 3 AP. The mobile device is located by the intersection point of 3 circles. Each circle has for radius the distance between the mobile device and the considered AP as illustrated in Fig.2.12.

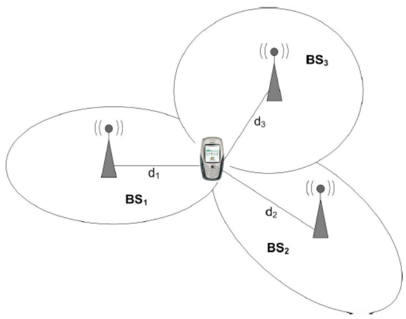

Figure 2.12: Signal strength trilateration technique.

A Microsoft Research group has developed RADAR system, [25] a building-wide tracking system based on the IEEE 802.11 wireless networking technology. RADAR measures, at the base station, the signal strength and signal-to-noise ratio of signals that wireless devices send, then it uses this data to compute the position within a building. Microsoft has developed two RADAR implementations: one using scene analysis (predictive model) and the other using lateration.

RADAR's scene-analysis implementation can place objects to within about 5 meters [25] of their actual position with 50 percent probability, while the signal strength lateration implementation has 4.3-meter accuracy at the same probability level. Although the scene-analysis version provides greater accuracy, significant changes in the environment, such as moving metal file cabinets or large groups of people congregating in rooms or hallways, may require reconstructing the predefined signal-strength database or creating an entirely new database.

2.2.5 Radio Based Location Techniques : Conclusion

In this section, it were exposed the most commonly deployed techniques in Radio-Frequence (RF) location. As seen, some concepts of the techniques are always linked, as in example the Predictive Modelling with Signal Strength, and despite their differences they complement each other.

Angle-Based techniques and Time Of Arrival (ToA) have characteristic's that increase the difficulty from beeing used in a NLOS indoor environment and the small distance for the ToA these cannot be used in a building-sized are as a GLS.

SS and trilateration, have good properties for small areas and could be used by largely deployed technologies such as Wireless Lan (802.11) as an IPS, using the same scope as RADAR.

2.3 Location Process Algorithms

This section, describes the algorithms and techniques used in the localization process to acquire the desired position for indoor systems. After addressing the Systems and the Techniques, the Algorithms sustain the computation process that gives relevance to the data and allows for the positioning to be a location; as described earlier this reflects a position with meaningful information to the user/requester.

The section is comprised of three main algorithms: the Nearest Neighbour (NN), a commonly used algorithm for nodes distance comparison; the Trilateration, a mathematical approach to positioning using the Euclidean distance; and Fuzzy Logic, a many-valued logic algorithm that enables for a wider rule-set in determining the positioning.

2.3.1 Nearest Neighbour

Highly connected with the fingerprinting due to the need of a data base for comparison, this algorithm uses the information of the surrounding nodes to map, using a radio map database, the current position [39].

This is the base for the Nearest Neighbour (NN) approach, it does not required previous knowledge of the physical location of the access points/nodes; but it requires an extensive mapping, a grid of all positions on which a location can possibly be rendered, as seen in Figure 2.13.

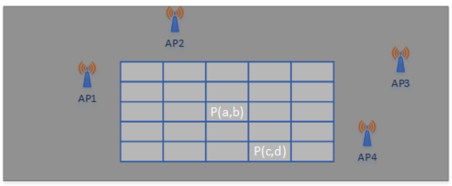

Figure 2.13: Illustration grid premapping of the signals scanned in each cell for unknown access point locations.

The algorithm works by correlating the scanned signals with the pre-mapped signals, and returning the cell on which the values are more similar as the final position.

2.3.2 Trilateration using RSSI (Euclidean)

This algorithm is the base for RSS systems being already available for usage in WLAN networks, without any further changes in the infrastructure.

The distance between two nodes can be estimated by measuring the energy of the received signal at one end. This distance-based technique requires at least three reference nodes to determine the location of a given node and the exact physical location of the nodes. This technique uses a the euclidean distance in space algorithm to determine the location of the mobile unit, as depicted in Figure 2.14. The dashed circles illustrate various levels of RSS measurements.

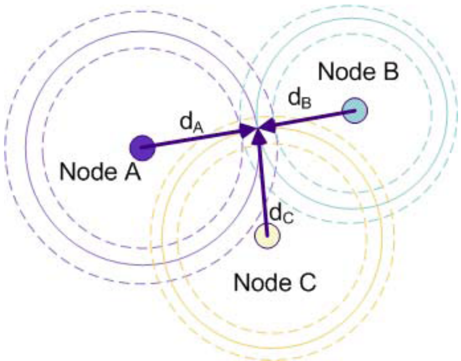

Figure 2.14: Illustration of positioning via the trilateration of three RSS measurements from nodes A, B and C.

2.3.3 Fuzzy Logic

Fuzzy Logic[40] is a form of many-valued logic or probabilistic logic; it deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets (where variables may take on true or false values) fuzzy logic variables may have a truth value that ranges in degree between 0 and 1.

Using Fuzzy Logic in IPS means constructing a set of rules that will balance the trilateration algorithm outcome. By attributing values to different characteristics of the computation, this algorithm can take into account for example, nodes that have bad positioning (against a steel wall), and on-the-fly create a set of possible positions to be adjusted by the given rules.

2.3.4 Location Process Algorithms : Analysis and conclusion

In this section it was discussed the most used algorithms to process information within specific systems and calculate the desired position, the discussed algorithms were strongly focused on indoor radio based location platforms.

The three explained algorithms are the most basic algorithms used in todays IPS, the nearest neighbours based on fingerprinting where there is no need to know the broadcasters position but a pre-mapping survey is required, the trilateration where the broadcasting positioning is required, and the fuzzy logic, which tweaks a system algorithm in order to achieve better results by understating the environment layouts.

All of the algorithms rely on measuring RSSI, but can be usable using the Dbm power rating, or any kind of power measurement available.

2.4 State of the art: Conclusion

The elaboration of this chapter along with its contents, allows for the understanding of current techniques and technologies used in Geo-Location giving a great emphases on indoor position location. Understanding the gap between current GLS and their use for indoor locations makes a clearer point into the room and opportunity of this dissertation.

As observed, the main problems with IPS are NLOS and technology deployment: GPS and CN are well performed systems that even with the incapacity of functioning indoor, have an added value in the field of technology deployment. Asymmetrically, UWB is a serious promise in to filling the gap, but the lack of standards makes this technology less deployed and used, leaving WLAN the best trade-off between technological capability's and indoor deployment.

In the techniques field, the usage of multiple concepts is always present. Even in Angle-Based location, the usage of fingerprinting and signal-strength is of importance, to achieve a better accuracy. As Angle-Based is not a standard in WLAN, the proposed techniques should be fingerprinting, signal-strength and Co-Similarity (Co-Sim).

In the next chapter the proposed solution renders a systems that uses WLAN with fingerprinting, signal-strength and the similarity between nodes, adding an element of pre-mapping locations. This pre-mapping locations refers to working with previously defined fingerprinted points as the base-nodes in order to compute the location.

A rigorous evaluation is required of this system, in a strict engineering point of view the limitations, performance and robustness are the most significant. As an GLS, the complexity, implementation cost and usage are very important characteristics. Both types of evaluation will determine and clearly define the outcome of a ubiquitous wireless indoor positioning system.

3

Proposed Solution

Contents

This chapter discusses the proposed solution taking into account the research done in the state-of-art. The proposed solution is agnostic to the implementation details.

The solution is a client-server platform that uses the WLAN to offer positioning and guidance services. It allows the requester to see his position inside a building, and to request orientation from his position to a specific room. In order to calculate the position of the requester, two key-processes were defined: the Update Access Point Signals, where the requester sends the information of surrounding broadcasted Access Points signals and (if available) geo-magnetic orientation; the Request Position, where the requester asks for his position and visualizes it in his device.

Taking the state-of-art Location Processes into consideration, both the Nearest Neighbour (NN) and the Trilateration had expensive requirements, one required a full mapping of the possible position places, and the second required the physical position of the Access Points. In order to achieve a better trade-off for the positioning process of the platform, it was designed the Nearest Neighbours and Trilateration with pre-mapped points (NNTP) as an alternative that uses the NN similarity approach with the Trilateration estimative pinpoint.

The NNTP does not require the extensive mapping of the NN, mapping as few points as possible and uses these points the Trilateration method (the Euclidean distance) as a way to find the possible position. Using the digital compass common in mobile devices, the ”North point” and the desired location, the platform provides orientation from the requesters current position to the destination. By having the three points, the platform calculates what is the angle that the requester should turn in order to be facing his desidered location rendering meaningful orientation to the requester.

This chapter is divided in two sections: the proposed platform that defines the platform which supports the objectives and the proposed location processing which deals with the locations algorithms and techniques that the proposed platform uses in order to achieve the solution features.

3.1 Proposed Platform

In this section the proposed platform is discussed. The platform is the sum of the modules, layers, and their interoperability that serve as the supporting base to achieve the offer of features previously detailed. For the objective of the proposed platform to be extensible, ubiquitous and easily implementable its architecture is highly modularized, consisting in several individual modules discussed further ahead that are responsible for individual tasks providing abstraction.

Taking a top-down view into the platform, the main architecture along with its required modules is explained first, afterwards the two most important operations, the signal update process and the request position are discussed.

3.1.1 Platform Architecture

The architecture of the proposed platform relies on the conceptual layering, the modules and their interoperability.

The proposed architecture is based on a client-server model. To create the abstraction between the communication to/from the client and the operations of the service, two layers were defined, the Platform Layer and the Positioner Platform Layer. These two layers define the levels of interaction between two entities abstracting what the entities are aware: the Platform Layer, where the client is aware of the service and requests operations from it; and the Positionr Platform where the Platform layer is aware of the Positioner services and forwards it the clients request for processing. This relates directly with the ubiquity and extensibility of the required features. Having one service which to request the operations allows for larger types of access enhancing the ubiquitous property of the platform, and the separation allows for individual layers to expanded or reduced without compromising the rest of the offered features/services.

The modular approach into this platform, as seen in Figure 3.1, enables for a better understanding, extensibility in the future and provides a clear differentiation in project-wise operations.

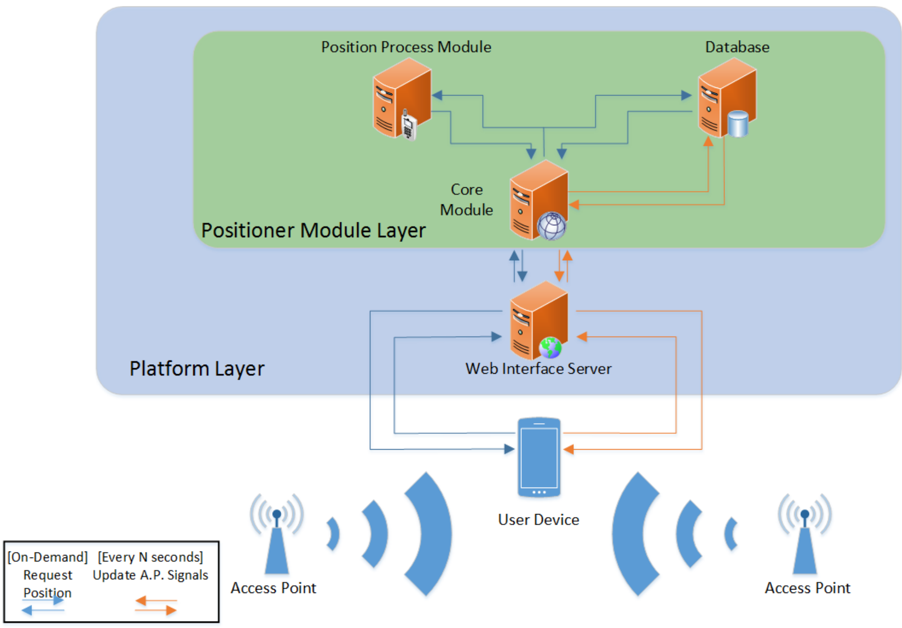

Figure 3.1: The main layers of the proposed solution, the main access platform layer and the location process layer.

The two key processes and the responsible modules are depicted in Figure 3.1. In blue lines, the Request Position and in orange, the Update Access Point Signals. The Update Access Point Signals, is a process responsible for sending the informations of broadcasted 802.11 access point signals in the requesters surroundings to the platform; and the Request Position is the request that asks the platform where the requester is. The requester communicates only with **Web Interface**

Server that ensures a single point of access for requesting the platform operations. In turn, the **Web Interface Server** forwards the requests to the **Core Module** that orchestrates the **Database** to save information or to retrieve information feeding it to the **Position Process Module** in order to request the position computation.

The **Web Interface Server** is the main module responsible for receiving and responding to clients requests and providing interaction. As a separated single entry point, and as responsible for the communication to the platform layer, this module can be replicated (if needed) multiple times into the layer providing extensibility and robustness. This module can be modified to respond to different types of communication requests, HTTP, HTTPS or any type desired, (given the same nature of inputs) and still be valid to respond to the proposed solution objectives, rendering an added-value to the ubiquity properties of the solution.

Being responsible for orchestrating the operations related with positioning, the **Core Module** is the main module in the positioner layer. This module communicates externally receiving requests or sending the results of the operation with the web interface module; and internally by handling the process between the internal modules to achieve the requested operation result.

In order to respond to the key-feature of position determination while maintaining the abstraction degree, the **Position Process Module** is an individual module that executes the computation process of calculating the position. Orchestrated by the core module and with the information given by the database, this position process module is able to, given the positioning calculation technique, determine the positioning of a client upon its request.

The **Database** module is not a database itself but an entry-point to the communication to the database. Using this separation enables for the use of different types of databases and allows for extensibility in the long-run.

3.1.2 Platform Key-Processes

The proposed platform key-processes architecture are the high level component overview of the interactions between the modules. These models render the required features to operate successfully within the determined requirements. There are two main processes required for the proposed solution to achieve its goals, the update of access point signals that works as the input of information by the requester concerning its surroundings (which can work as a pre-mapping tool); and the request of position that triggers the location process and returns the requesters position.

As mentioned earlier, there is one entry point for communications to the platform, the Web Server. In order to easily extend the platform key-services, it was decided to use the JavaScript Object Notation (JSON) as the preferred method for information notation. The JSON format is fully compliant with the Hypertext Transfer Protocol (HTTP) protocol used in the Web Server, and the Database stores this type of information as a single object independent of what it contains.

This allows for several other informations to be added in the communication payload without having impact in the created processes. This flexibility is used in order to obtain the geo-magnetic information for the guide process, if this information is available then it should be sent in the payload as an extra field, if not, then the field does not exist in the sent payload.

The guide process functionality of the platform, is not described here because it is viewed as a proposed extension to both of the main key-processes, being explained in the Proposed Location Processing section. On one hand it extends the update access point signals to retrieve the geo-magnetic orientation and on the other hand it uses this information along with the calculated position and the desired location to be guided to inform the client what direction should he follow. This separation is exemplifies the extensibility of the proposed platform.

3.1.2.A Update Access Point Signals

The update access point signals is the key-process that concerns the retrieval/update of the information relative to the AP signal strength in the clients surroundings. By constantly updating this information the proposed solution is able to be ready at any time to render the position upon request.

This key-process allows the platform to receive and save the users information. The saved information is timestamped, user-identified and it is not limited to one type of format, because of the flexibility given by the Database module and the chosen JSON format, the information can have two different payloads, the 802.11 scan of signals and the geo-magnetic orientation.

In Figure 3.2 the modules flow for the request of positioning is depicted. The update from a requester is made to the Web API, which forwards to the Indoor Position API to orchestrate and waits the response. The Indoor Position API registers the information with the Database and once the operation is confirmed the Indoor Positioni API queries the Json for a formatted response which is forwarded to the Web API and to the requester.

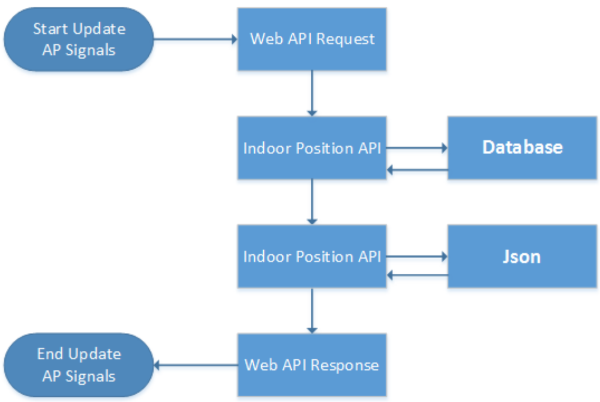

Figure 3.2: The request flow between the modules for the update of access points signals.

Providing a more thorough description at the module level:

Offering different requests-of-service, the **Web API Request** is the Web Server Interface described earlier. In this context it receives the information of the power statuses of nearby AP signals and geo-magnetic information (if available) that are retrieve by the requester. This information is forwarded to the **Indoor Position API** which is the Core Module that orchestrates the Positioner Module Layer and for this process it stores/updates the information with the **Database** module. Once the information is acknowledged as kept (or failed to keep), the result is sent back to the Indoor Position API which requests the **JSON** to format the response accordantly and forwards it to the Web API as the response.

3.1.2.B Request Position

The request position is the key-process that concerns the request to the current calculated position to the proposed platform. Using the information given by the client while in the update signals process, the request position process can be executed by the proposed platform and returning the calculated position to the client which is represented by the web API.

In Figure 3.3 the modules flow for the request of positioning is depicted. The request from a requester is made to the Web API, which forwards to the Indoor Position API to orchestrate and waits the response. The Indoor Position API retrieves the information relative to the requester from the Database and sends it to the PositionFinder waiting for its return. Once the positioning is calculated the Indoor Positioni API queries the Json for a formated response which is forwarded to the Web API and to the requester.

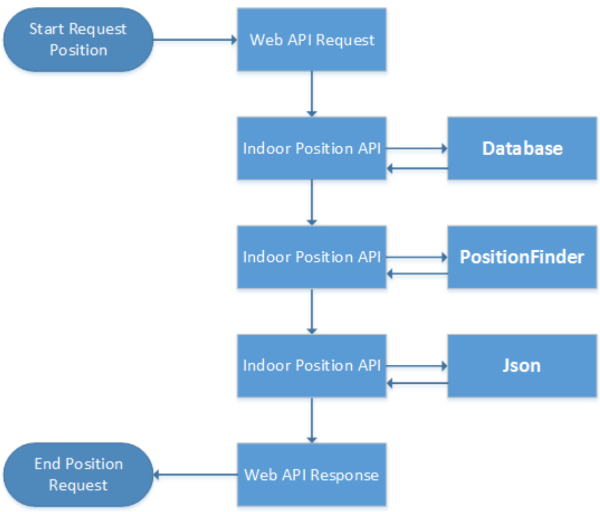

Figure 3.3: The request flow between the modules for the request of position.

A more thorough description at the module level: Offering different requests-of-service, the **Web API Request** or the Web Server Interface as described earlier, in this context offers positioning to the requester. It receives the request that has the user identification and timestamp attached, and forwards this request to the **Indoor Position API**, the Core Module for positioning.

The Indoor Position API queries the user information from the **Database** module, and requests the current position of the user to the **Position Finder** while also feeding the user retrieved information. Both position finding and guidance process follow this same process, with the difference that for guidance an additional destination information is in the Position Finder received request. The Indoor Position API receives the calculated position from the Position Finder and forwards the information to the **JSON** that formats the response accordantly and the response is dispatched to the Web API.

3.2 Proposed Location Processing

This section discusses the proposed location processment for the solution. The location processing algorithm is the process in the proposed platform defining the processing the final positioning of the requester and for processing the guidance information that the requester should receive.

3.2.1 Nearest Neighbours and Trilateration with pre-mapped points

The proposed location process is the combination of the Nearest Neighbours and the Trilateration algorithms in order to maximize the flexibility in the process while reducing the requirements.

By combining both location processes, the resulting algorithm requires a survey, but not a full extent grid-survey and can use the trilateration euclidean (or any sub-variation) calculation for achieving a finer granularity to the possible calculated positions.

The proposed visualisation for this approach is seen in Figure 3.4. Where the AP are in an unknown physical location, and a hollow grid with the surveyed points is constructed.

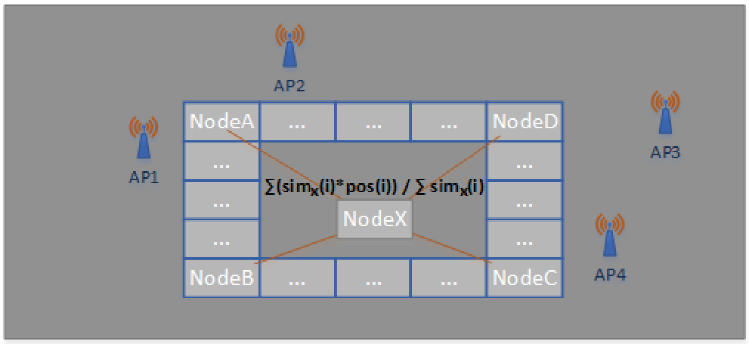

Figure 3.4: The proposed location algorithm with the pre-mapped positions (each Node A-D) rendering the position of Node X through the formula

The image above depicts the high-level view of this algorithm, as said before the location for each AP is not known; the nodes location and scan are known and used as a location base data for the proposed system; and to calculate the position of the requester the formula 3.1 is used.

To render the location with the node information the equation 3.1 can be used. Using the pre-mapped nodes locations and pondering them with the similarity to the unknown Node X its position can be calculated.

$$pos(NodeX) = \frac{\sum_{i=NodeA}^{NodeD}(sim_X(i) * pos(i))}{\sum_{i=NodeA}^{NodeD}(sim_X(i)} \quad (3.1)$$

Equation 3.1 determines the position of Node X ($pos(NodeX)$) by adding all the positions resultant from the multiplication of, the position of know Node i with the similarity of Node i with Node X ($sim_X(i) * pos(i)$) and dividing it for the sum of similarities between Nodes i and Node X .

The proposed algorithm requires a pre-mapping of the area which renders into a position/access-point-power database. Afterwords, when a positioning is requested, the requester must send its scan of the surrounding signals; this allows to compare the scanned signals with the database, through similarity (as seen in Table 3.1) and the euclidean distance it renders the requested position.

	AP_1	AP_2	AP_3	Node Location	Similarity Node X
Node A	val$_A$(AP_1)	val$_A$(AP_2)	val$_A$(AP_3)	pos(A)	sim$_X$(A)
Node B	val$_B$(AP_1)	val$_B$(AP_2)	val$_B$(AP_3)	pos(B)	sim$_X$(B)
Node C	val$_C$(AP_1)	val$_C$(AP_2)	val$_C$(AP_3)	pos(C)	sim$_X$(C)
Node D	val$_D$(AP_1)	val$_D$(AP_2)	val$_D$(AP_3)	pos(D)	sim$_X$(D)
Node X	val$_X$(AP_1)	val$_X$(AP_2)	val$_X$(AP_3)	TBC	N/A

Table 3.1: The theoretical table of nearest neighbours similarity and location with the To be calculated (TBC) unknown Node X

This is a proposed example of the pre-mapped points from A to D and the To be calculated (TBC) NodeX. The columns AP_1, AP_2, AP_3 represent the measured power; each of the nodes A-D have a known position in the Node Location column, and for each, the similarity with Node X is calculated; after, the euclidean distance between the positions is weighted accordantly with their similarity to Node X and its position is rendered.

One of the key variables of this proposed location process is the physical distance between the pre-mapped nodes. This is the distance between the ”measurement” point that survey the area and create the Nodes. Which should depend on the implementation, specifically on the area where the project is implemented.

3.2.2 Location Guidance

The Location Guidance is a proposed location process that guides the requester from its current calculated position to the location target which was required.

This guidance is a process which heavily relies on the location of the requester, and as such it is structured as a proposed location process and is not inserted in the key-processes of the proposed platform.

The process works by having the current location of the requester, the desired location and by having the geo-magnetic orientation of the device. These informations allow to calculate the angle to which the device should rotate in order to face the desired location. In Figure 3.5 it is explained how the rotation angle works and in equation 3.2 the theoretical equations for this calculations are shown.

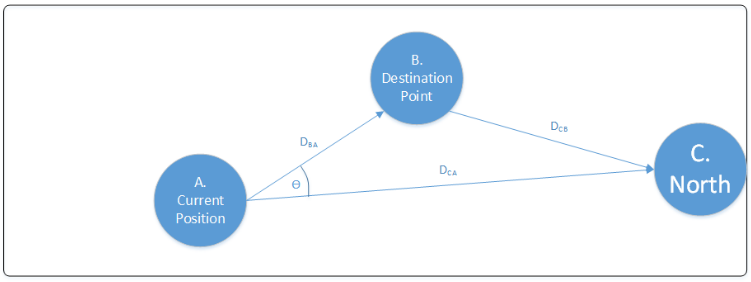

Figure 3.5: The angles used for finding the rotation angle on which the requester should turn in order to be facing straight at the desired location.

The above Figure displays the three important positions to calculate the angle which the device should turn in order to face the desired destination point. Point A is the calculated current position of the requester, Point B where the requester desires to be guided and Point C is the North point, which is a point where the requesters device holds its geo-magnetic variance.

By having the information of the variation to the North point, and knowing the position of the three points, equation 3.2 can be used to calculate which is the angle that the proposed platform module for requester visualization should rotate in order to offer guidance.

$$
\begin{aligned}
D_{BA} &= \sqrt{(A_x - B_x)^2 + (A_y - B_y)^2} \\
D_{CA} &= \sqrt{(A_x - C_x)^2 + (A_y - C_y)^2} \\
D_{CB} &= \sqrt{(B_x - C_x)^2 + (B_y - C_y)^2}
\end{aligned}
\tag{3.2}
$$

$$
RotationAngle = \theta = \arccos \frac{BA * BA + CB * CB - CA * CA}{2 * BA * CB}
$$

By knowing all the positions, calculating their distances (D_{BA}, D_{CA},D_{CB}) and applying the rotation angle (θ) to the North orientation of the requesters device will it point directly to the requested guidance point.

3.3 Proposed Solution: Conclusion

The proposed solution is a modular client-server based platform, that in order to provide the extensibility and ubiquity was design with two abstraction layers in its architecture. Defining the single points of communication, the Platform Layer and the Positioner Module Layer allow to extend the platform without compromising the whole process structure. Two key-processes where defined: the Update Access Point Signals and the Request Position. The first is the process that receives and stores area information about the client; the second calculates the position of the client through the proposed NNTP algorithm, and uses the the location guidance to offer orientation from the clients current calculated position to the desired location.

In order to lower the implementation requirements of the solution, the hybrid algorithm NNTP uses the NN grid-alike nodes and the Trilateration pinpoint to calculate the position of a client. This positioning is used for the guidance process as the current position along with the destiantion position and the North position to calculate what is the angle that the client should rotate to be facing the desired location.

The usage of the platform requires the visualization of the position location in a friendly and local-aware way. This will also be used by the guidance service to display the correct direction to the destination.

The proposed solution should render four core modules that are responsible for calculations of position, communications, storing of informations and interactions. This modularized implementation directly relates with the ubiquity and extensibility required, allowing for the platform to be created with clear and concise modules and accessible using the defined layers/entry-points.

4

Implementation

Contents

This chapter details the implementation of the proposed solution.

The indoor area of the Instituto Superior Técnico - Taguspark (IST-TP) was the test site for the implemented solution. This chapter discusses two topics: the IST-TP environment analysis and the implementation of the solution. The Environment Analysis describes the characterization made to the WLAN signals inside the building. It also discusses the analysis of the used instruments and how they were used for the solution implementation.

Rendered a fully working Indoor Positioning systems (IPS) solution, the IndoorPositionr Platform implementation section discusses the aspects proposed in Chapter 3, namely the Architecture, Key-Processes and Locations Process Algorithm.

4.1 Environment Analysis

In this section it is discussed the Environment Analysis where the proposed solution was prototyped.

The Environment Analysis is the characterization of the area, analysing in terms of signals behaviour and detailing the used tools for this end. This section is divided into two subsections, the 802.11 capability analysis for the signals behaviour, and the Analysis tools, where the tools built for this platform are discussed.

The main and southern lobby area of the floor 0 in Instituto Superior Técnico - Taguspark (IST-TP) was chosen as the environment on which the proposed platform was implemented. This area was chosen since it is composed of two main sections, Area 1 with a wide and obstacle free zone and Area 2 with less line-of-sight as depicted in Figure 4.1.

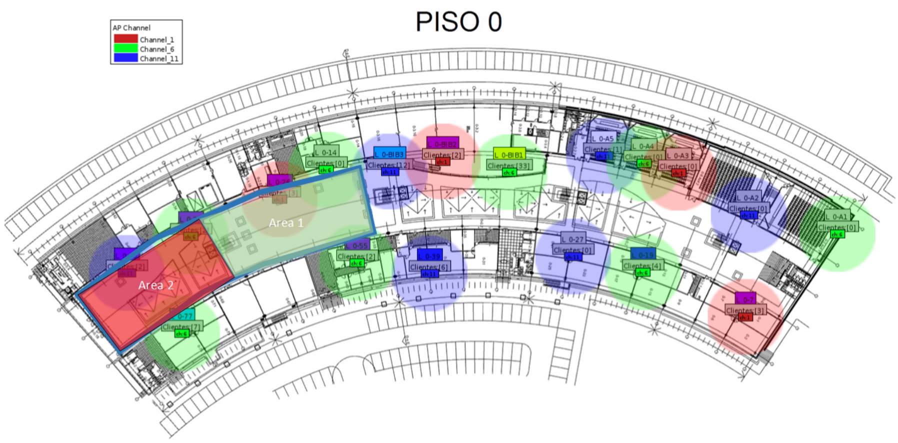

Figure 4.1: The area of the implemented project in IST-TP.

4.1.1 Instruments Analysis

In order to understand how the tools used for this project would behave, a characterization concerning their limitations was made.

During the implementation of process, several tools-iterations were made, and on each the tools analysed and improved. The first iteration was concerning the behaviour of the 802.11 signals, and where the Wlanlist was created, in the second iteration the IndoorPositionr API was created. And in the third iteration the IndoorPositionr Platform is defined.

Wlanlist

Written in Python 2.7, this tool was created using by loading an Windows native dll and adressing its system-space calls into the Python workflow. This allowed to scan and characterize the 802.11 signals but due to the used laptop hardware limitations each wireless channels broadcast scan took a maximum time of 4s.

IndoorPositionr API

Using Python 2.7, Flask webserver API, Javascript Leaflet platform, a new laptop and the knowledge acquired of Wlanlist, this tool was created to assess with visual help of location inside the IST-TP the 802.11 signals in various points. Due to the new wireless hardware the broadcast scan time of all wireless channels was reduce to a maximum time of 1s.

IndoorPositionr Platform

Using the same instruments above and adding an Android 4.2 Galaxy s4 mini and Amazon Elastic Computing as the cloud-server, the full platform was implemented. With the restrictions of a maximum of 1s between scans and requiring the geo-magnetic information from the mobile device

The tools had an organic growth. The first tool (Wlanlist) allowed to inspect the signals variation for one specific AP, and had a 4 second maximum time of scan. This created two problems: the information had to be analysed for each AP, and with (at least) 46 broacasting sources it was overwhelming to discern; and the 4 second was too high for keeping track of a moving person position.

The change of laptop allowed to use a different wireless network device. This device took a maximum of 1 second to scan all the channels and report back. The new hardware along with the early development of the IndoorPositionr API allowed to retrieve and analyse multiple beacons in almost-realtime. The visualization provided by the Leaflet Javascript now showed the floor of the IST-TP and the analysis could have meaningful information location-wise.

Despite being fully working, the platform was restricted to one laptop, which had no geo-magnetic information. The provided solution was to iterate the tools once again, to expand its usage to a cloud server and a mobile device. By deploying the service layer in the Amazon Elastic Computing and creating the application for the mobile device the fully working platform could now serve multiple users and be used to test the guidance module.

4.1.2 802.11 capability analysis

In the analysis of the 802.11 capability for the proposed solution implementation the characterization made to the environment concerning the Wi-fi signals broadcast at the IST-TP area, is discussed.

The analysis was made in order to understand what is the medium minimum distance at which the signal broadcast is perceived, as discussed in the Signal Strength: Minimum Perceivable Distance, and to understand how do signals behave collectivity when walking in a straight line.

This allows for the characterization of the signals and to establish a minimum distance point between the survey point discussed in the previous chapter, the pre-mapped points regarding the Location processing algorithm, the NNTP.

4.1.2.A Signal Strength: Minimum Perceivable Distance

In order to understand how the distance to an AP infers in the Received Signal Strength (RSS) it was necessary to implement an analysis of this phenomenon. Using the first set of tools Wlanlist as stated above, in the main lobby (Area 1) of IST-TP a set of scans were made; Using 1 meter as the minimum distance, as it is represented in Figure 4.2, a total of 56 positions were scanned, in all channels to analyse the variation of RSS in a small area.

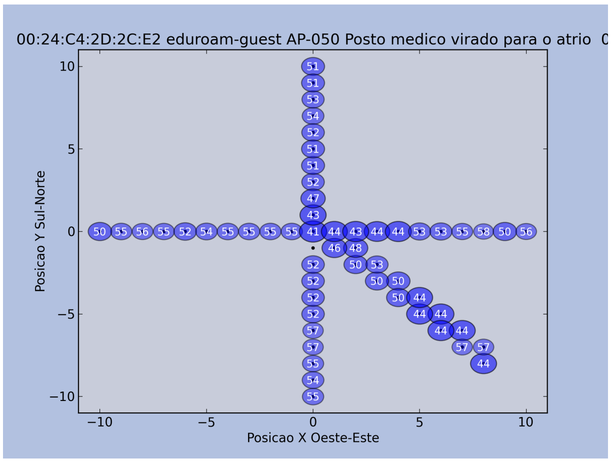

Figure 4.2: Example of the signal strength variation of the AP-50 (Medicals Office)

In this analysis 46 different Media Access Control (MAC) addresses broadcasting their signal were captured. This particular signal, comes from one of the AP-50 near the Medicals Office, which at the time was the closest AP to the measuring area. Figure 4.2 shows the minimum variation of 4-meters, as shown in the negative X axis and the negative Y axis.

This first analysis rendered the possibility of a 5-meter mark for a perceivable change in the received signal strength of a given AP. Although informative there was too much information in the environment not being processed, namely the remaining 45 MAC broadcasting addresses. This necessity led to the iteration of the Wlanlist tool in order to harbour more information, creating the IndoorPositionr API.

4.1.2.B Signal Strength: Signals Environment

The following analyses the achievable Minimum Perceivable Distance, in which a wider range of components were analysed.

Using the information regarding the mapping of AP the broadcasting MAC addresses were filtered, discarding other broadcasting addresses. Two wireless routers, Alpha_Beacon and Beta_Beacon, were placed in the end of the two axis Y and X respectively.

Figure 4.3 represents the basis for the analysis, in Figure 4.3a) it its shown the graphic for the median variation of the signals for each AP, where each node has wider radius depending on the signals variation for that position. Because of the high number of points to plot, just those with a deviation greater than 5 RSSI from the last position are shown. Figure 4.3b) depicts the area of analysis with the representation of the used AP. The green line represents the path taken inside IST-TP, from near the Alpha_Beacon AP represented in red to near the light green point which represents the AP-50 AP.

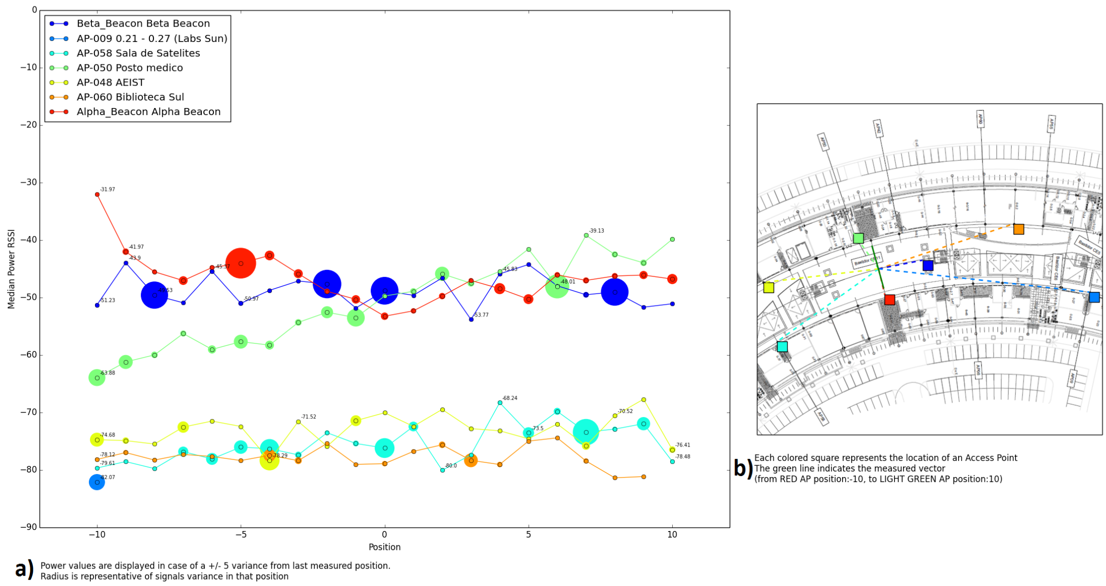

Figure 4.3: Signal strength variation of the 0-floor APs

Considering the light green line from AP-50, the closer the measurements are to the AP the stronger the signal is received; even though in the [6-10] position the Alpha_Beacon signal is strong, this error is attributed to reflection effects. The blue line is somewhat stable, as expected since the distance to the Blue_Beacon stays relatively the same.

One other consideration is made to the lower RSSI of the chart, namely the AP-058, AP-060 and AP-048, given their distances there is a clear separation to the closest AP. In this lower tier values, the behaviour of the light blue line, the AP-058 increases in strength since the higher measurement positions offer a better line of sight to the AP which is expected.

In the overall this analysis shows that the further away the measurement is taken the lower is the SS; some reflection effects could explain the variations when further away from the AP but closer to a wall, rendering a good model for analysis.

4.2 IndoorPositionr Platform

In this section the implemented platform named IndoorPositionr is described. The IndoorPositionr platform is the functional implementation of the proposed solution taking into account all topics discussed earlier.

The implemented platform offers the position determination, visualization and location guidance features in a ubiquitous and extensible environment while respecting the necessary requirements. After surveying the area (using the platform tools), the IndoorPositionr is ready to locate a client, update its location and guide him to one of the pre-designed locations.

This section starts with a top-down overview of the implemented platform, detailing the implementation of the key-processes, an explanation of the base location data in this context and the explanation of the implementation of the location process algorithms.

4.2.1 Platform Architecture

The implemented platform has a ubiquitous, extensible and easily deployable architecture divided into four main modules.

Responsible for the single entry-point of the communications, the Web API deals with the external communication to the platform services. Providing the positioning and guidance services, the IndoorPositionr module orchestrates its internal modules to respond to the platform services.

On the client side, two modules were created: the Client Browser, that serves the Interaction and Visualization modules; the Client IndoorPositionr, a service that continually send the clients information to the platform. Creating the user visualization and its interaction with the platform services, the Client Browser module allows for the user to trigger the operations request to the platform. Serving the WLAN scanned and the geo-magnetic informations, the Client IndoorPositionr enables for a routinely relay of the uses current signals to the platform.

As seen in Figure 4.4 the platform is compartmentalized in modules which function to serve a individual purpose, and in types of communication that give a better understanding on which level those modules communicate.

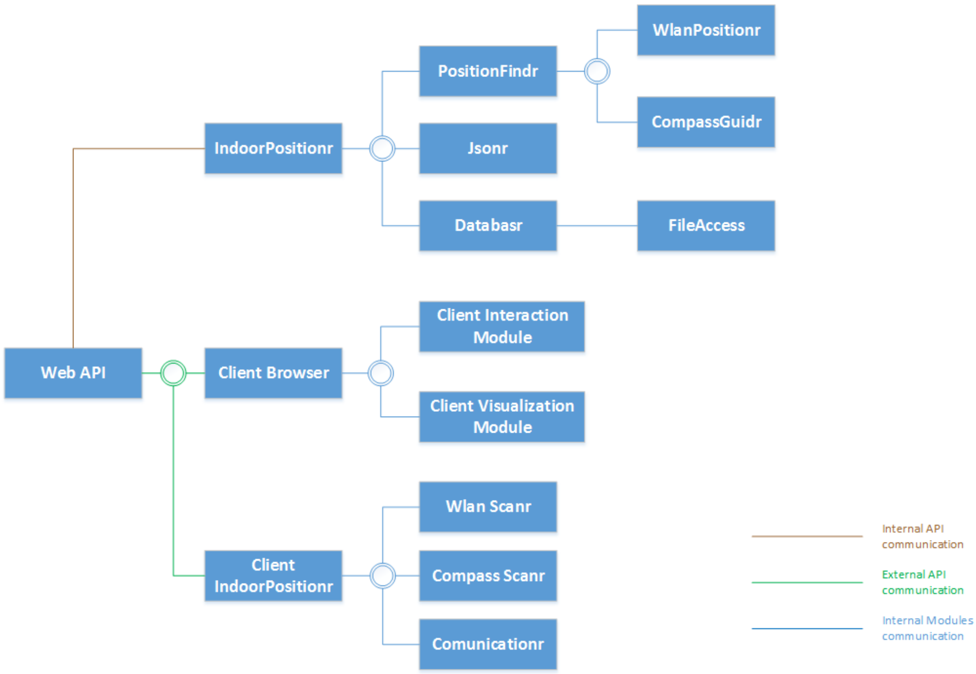

Figure 4.4: The architecture of the IndoorPositionr Platform with the communication types between modules.

The three communications types are viewed in Figure 4.4 to better understand the implementation done in the platform. The Internal API communication (in red) represents the communication between the Web API and the IndoorPositionr core module, the single entry-point on which the web requests are relayed to the servicing-offering-platform. The External API communication use HTTP requests with the JavaScript Object Notation (JSON) formation as payload and connect the Client Browser and the Client IndoorPositionr to the platform, using the Web API as a medium. The Internal Modules communication use normal calls and responses for each technology environment.

Both of the External and the Internal communication carry the identification of the user and timestamps in the requests, and as such, the platform supports multiple users at the same time.

The following describes each module and their function in the implemented platform.

Web API is the core communication module in the platform. It receives all the communications from the client (externally) and relays them in requests to the core IndoorPositionr module. This module directly relates with the proposed Platform Layer by being the single entry-point of request to the platform services. Using HTTP communication and JSON payload allowed to seamlessly transport requests from the external clients to the IndoorPostionr module.

IndoorPositionr core module renders the key-processes of the platform, receiving all the requests from the Web API. As the proposed Positioner Module Layer, it orchestrates the PositionFindr, Databasr and Jsonr modules in order to perform and serve the requested operations.

PositionFindr is responsible for processing positioning in the platform. It receives the requests from the IndoorPositionr along with the necessary database information and renders positioning or guidance using WlanPositionr and CompassGuidr.

WlanPositionr calculates the position in the platform. It receives the request from the PositionFindr along with the necessary database information and calculates the respective position by using the NNTP algorithm.

CompassGuidr calculates the correct orientation for location guidance. It receives the request from the PositionFindr containing the necessary user geo-magnetic orientation and WlanPostionrs user position, to calculates the orientation that should be provided to the client in order to direct him to the desired location.

Jsonr is the module responsible ensuring compatibility in the IndoorPositionr responses. It receives the request from the IndoorPositionr with the information to respond and formats that information in a easy and understandable way to the Web API to relay to the external communications.

Databasr allows for access and storage of the permanent information. It receives the request from the PositionFindr and manipulates the information in accordance. For prototyping usage, the module reads and writes to a file. Nevertheless, it is prepared to read and write seamlessly to a non-relational Database engine.

FileAccess is the module responsible of accessing the physical files of the database. It receives the request from the Databasr handles the physical files operations.

Client Browser in the platform this is viewed and treated as a module, but it is a third party appliance commonly installed in every mobile device. Using the native Browser Javascript technology modules are loaded into the regular Browser that allow it to function as the main tool to provide the client with visualization and interaction with the rest of the platform. It sends and receives the operations with the Web API and relays them to the Client Interaction and Visualization modules.

Client Interaction Module is the module responsible for the client interface response. It creates, listens and dispatches the clients requests and upon receiving the responses requests the Client Visualization Module to display them.

Client Visualization Module is the module responsible for the client interface visualization. By using the Javascript Leaflet it renders all the visual information in the Client Browser for the users consumption.

Client IndoorPositionr serves crucial client-side WLAN and geo-magnetic information to the platform. It orchestrates the requests of information to both the Wlan Scanr and the Compass Scanr, through the Communicationr crafts the requests to the Web API. In order to have a continuous stream of the clients information and due to the Android technology layers, this native Android application was required.

Wlan Scanr is the module responsible for the retrieval of the client side 802.11 scan information. It receives the request from the Client IndoorPositionr and responds with a scan list of the 802.11 signal broadcasts. By accessing the Android Network Layer the Wlan Scanr can request the Android Platform to scan the area and retrieve the results.

Compass Scanr is the module responsible for the retrieval of the client side geo-magnetic information. It receives the request from the Client IndoorPositionr and responds with the geo-magnetic orientation of the client. The magnetic orientation is retrieved by accessing the Android Sensor Layer.

Comunicationr is responsible for the communication to the Web API. It receives the request plus the data payload from the Client IndoorPositionr, crafts and sends the request to the Web API and returns the operation result.

For this implementation five main technologies were used, Python 2.7, Java for Android, Javascript and HTML+CSS. The Web API, IndoorPositionr and IndoorPositionr child modules were developed in Python with the nuance of using the Flask framework for the HTTP service in the Web API. The Client IndoorPositionr was developed in Java for Android. And all the visualization and interaction in the Client Browser is through the Javascript components in a HTML+CSS rendering.

4.2.2 Key Processes

The platform key-processes architecture are the high level component overview of the interactions between the modules that render the proposed features to operate successfully within the proposed requirements.

There are two main processes necessary for the proposed solution to function, the update of access point signals that work as the input of information by the client concerning its surroundings; and the request of position that triggers the location process and returns the clients location information.

4.2.2.A Update Access Point Signals

The update of access point signals key-process is the implementation of the Chapter 3 proposed process. Its objective is to receives the WLAN broadcasted signals from the client mobile device scans and the clients geo-magnetic orientation.

By running a background application in the mobile device named Client IndoorPositionr, the application scans the broadcasted signals and the geo-magnetic orientation, with the cadence of one second. The one second mark is referred because it is the maximum amount of time the mobile device takes to retrieve the information. It was also considered a good cadence for the update positioning of a walking person. After the compilation of information, the Client Indoor-Postionr renders an external request to the Web API supplying the client identification and the retrieved information.

A modular view of the process is described in Figure 4.5, where the fully-stepped process is described.

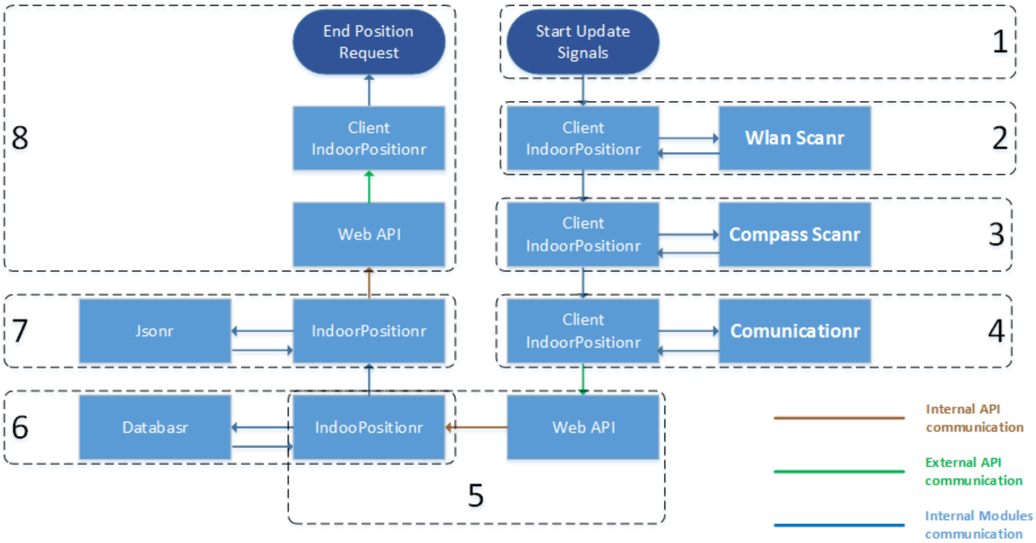

Figure 4.5: A modular view of the implemented process of updatig the 802.11 broadcast signals.

The description of the process is the following :

Step 1: Start Update Signals task is started by the Client IndoorPositionr.

Step 2: The Client IndoorPositionr requests the scan for 802.11 signals from the Wlan Scanr module.

Step 3: The Client IndoorPositionr requests the geo-magnetic orientation information from the Compass Scanr module.

Step 4: The Client IndoorPositionr sends the above received information to the Comunicationr module and requests the ready-to-send information.

Step 5: The Client IndoorPositionr requests the update of signals to the Web API which transforms the information and calls the IndoorPostionr module with this received information.

Step 6: The IndoorPositionr updates the stored information through the Databasr.

Step 7: The IndoorPositionr requests the Jsonr the response formatting for the received information from the Databasr operation.

Step 8: The IndoorPositionr responds to the Web API with the operation status which relays the information to the Client IndoorPositionr.

4.2.2.B Request Position

The request position key-process is the implementation of the Chapter 3 proposed process. The process renders the user-friendly, location-aware view of the clients position. Using the most recent information from the client stored in the Databasr, the process is able to return to the clients his location. If the request has a destination, then the location guidance is activated and a compass displaying the orientation is also displayed.

The request can be made in a one-time or using active/non-active stance. This allows for single time position request or a continuous position display. By default, location in the continuous mode have the minimum wait time of one second, which is the maximum time for the Client IndoorPositionr app to scan the surrounding signals.

The two main entities in this process are the Client Browser module that requests the position and displays the location; and the IndoorPositionr that receives the request and returns the calculated position based on its current and previous information.

A modular view of the process is described in Figure 4.6, where the fully-stepped process is described.

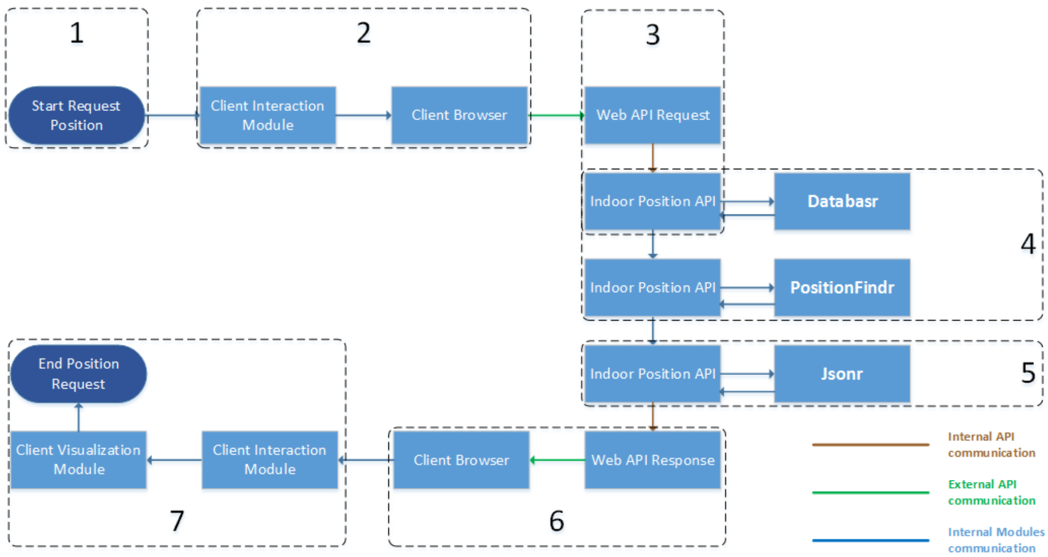

Figure 4.6: A modular view of the implemented process of the clients request position.

The description of the process is the following :

Step 1: Start Request Position task is started by the Client Interaction Module.

Step 2: The Client Interaction Module crafts the request along with the user identification and asks for the Client Browser to forward it to the Web API.

Step 3: The Web API transforms the information and calls the IndoorPostionr module.

Step 4: The IndoorPositionr requests the Databasr module for the clients information and feeds it to the PositionFindr module.

Step 5: The IndoorPositionr requests the Jsonr the response formatting for the received information from the PositionFindr operation and returns it to the Web API.

Step 6: The Web API relays the information to the Client Browser which in turn returns it to the Client Interaction Module.

Step 7: The Client Interaction Module interprets the information and requests the rendering of location to the Client Visualization Module.

4.2.3 Location Process Algorithms

The locations process algorithms are the core processes that render both services of location positioning and location guidance. The first uses the proposed method of Nearest Neighbours and Trilateration with pre-mapped points (NNTP) with a previous surveyed data to calculate the position of the client, while the second uses this calculated position and with the information of the clients geo-magnetic orientation offers guidance to the desired location.

4.2.3.A Nearest Neighbours and Trilateration with pre-mapped points

The Nearest Neighbours and Trilateration with pre-mapped points (NNTP) is the location process algorithm used in the implementation of the IndoorPositionr platform responsible for the calculation of a clients positioning.

In the implemented IndoorPositionr platform the PositionFindr is the module responsible for executing this algorithm. Fed with: pre-mapping points/signals, with the current client signals and (if available) the previous location. The PositionFindr uses the NNTP algorithm to render the position, which later is visualized as a location by the Client Visualization module.

In order to avoid large jumps of position, the PositionFindr takes into account the timestamp and the last calculated position of the client. With a small usage of the Chapter 2 Fuzzy Logic algorithm, a few rules were defined in order to minimize positional jumps due to signalling/environment errors. If the difference between the time of the request and the time of the last position calculation is smaller than 3 seconds, then the calculated position cannot more than 10 meters away from the last position. This numbers relate to the average human walking speed of 2.5 m/s.

For the NNTP to work, a previous survey of the area must be made, as show in Figure 4.8. These depicted points or nodes were used in this implementation as the basic location information. The reference/comparison nodes for the NNTP. Once this survey is available, the platform is ready to render the clients position.

Figure 4.7: The location of the pre-mapped points in IST-Taguspark.

The above image displays the location of the surveyed points used for this implementation in the area of IST-TP. These points are roughly separated by 5 meters and each of them was scanned fifteen times for a period of one second.

As discussed in the Results sections, in order to calculate the position of a sample scan of signals not all nodes can be used, in the tests done this rendered a always-centred point because of all the contributions as can be seen in Appendix A Figure 9 *Using all nodes*. The options was to use the top-N most similar points, which by evaluating (in section 5.1.1) lead to use the 5 more similar nodes for the given sample.

4.2.3.B Location Guide Compass

The Location Guide Compass is a feature implemented in the platform as a service that uses the clients current position and the desired room to offer orientation to the last.

The implemented process works by using the geo-magnetic compass informations along with the calculated position of the client (using the scanned signals) and returning the information on the angle which the displayed compassed should rotate in order do display the orientation to the desired room. The geo-magnetic compass informations are sent from the clients device in the same request as the key-process Update Access Point Signals, by adding the information in the request payload.

In Figure 4.8 it is seen the rooms that are available for guidance.

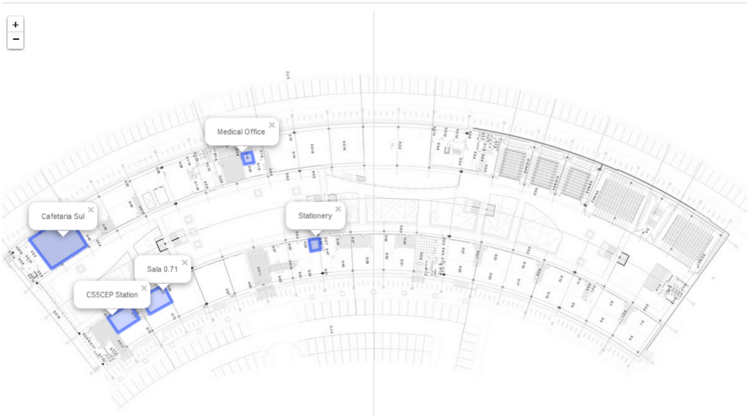

Figure 4.8: The location of the available destination locations.

In terms of implementation, the request guidance process is an activate/deactivate process started by the Client Interaction Module that follows the same module flow as the key-process Request position. The difference is that on the payload of the request the desired destination is added, and the response is changed to arbour the angle on which the displayed compass should rotate in the Client Visualization module .

4.3 Implementation: Conclusion

The implementation of the proposed solution was an organic, iterative process. Three iterations took place allowing the used instruments to characterize the environment and evolve to the final ubiquitous indoor positioning platform, the IndoorPositionr.

The first tool, Wlanlist, allowed to notice the slow scan rate (because of the hardware) and it was difficult to properly arrange the information of the scanned area. This demanded a second instrument that visually rendered better the information and had a higher rate of scan, the IndoorPositionr API. The third iteration was due to the lack of mobility, ubiquity and geo-magnetic information, rendering the IndoorPositionr Platform that was used as a the final implementation of the proposed platform.

In the environment analysis, the 5 meter mark was deemed as good ratio between the received power change and measured distanced. The signal analysis proved to be as expected, rendering continual gain or loss while approaching or gaining distance from the broadcasting source. When taking all the measurements an early assumption was made. The assumption that facing the AP directly or rotating a small angle could change the received power. The resulting graphic information seen in Appendix B, was a result of this test and proved that the received values did changed visibly.

This analysis allowed to characterize the IST-TP main and southern lobby in terms of WLAN signals and to provide the minimal optimal distance of five meters between surveyed nodes for the pre-mapping process.

The IndoorPositionr platform was build using the knowledge of the previous iterations and with a ubiquitous, easily deployable and extensible orientation. This rendered a platform highly modularized, with four core modules: The IndoorPositionr API where the positioning services are executed; the Web API responsible for the ubiquity in access and communication to the platform; the Client IndoorPositionr, a service which continually informs the platform of required data such as 802.11 signals or geo-magnetic information; and the Client Browser, where the crucial visualization and interaction for the client takes place.

The implemented platform has two key-processes, the Update Access Point Signals on which the client informs the platform broadcasted signals he scans, and the Request Position where the client request the location from the platform. To render its featured offered services, the platform uses the two location process, the NNTP for rendering the location of the client and the Location Guide Compass for displaying the direction for the desired destination. A set of rules were created along with the NNTP to accommodate error from signal interference. By taking into account the last calculated position when working in the current one, a radius of maximum range between them is inferred. This allowed for a better location positioning in the platform continuous location mode.

5

Evaluation

Contents

This chapter presents and discusses the evaluation made to the implemented solution.

In order to understand the validity and robustness of the proposed solution, the Evaluation chapter discusses the evaluation methods and results obtained.

By evaluating the accuracy of the positioning, both the validity and the robustness are tested. This first analyses aims to learn and dissect the positioning error. This error is the difference between the calculated position and the true position. In every Geo-Location Systems (GLS) the error for pinpointing the location is the most crucial factor in the system.

The used Top-N nodes in the Nearest Neighbours and Trilateration with pre-mapped points (NNTP) is one of the characteristics of the algorithm. The second evaluation targets the best number of nodes to be used in the implemented algorithm. This allows for an analysis of the behaviour of the algorithm itself.

In the third evaluation, the viability of the location guidance service is analysed. This evaluation allows to understand what are the positive and negative points for this proposed location process.

Taking into account the evaluations done to the GLS systems in the state-of-art, the proposed solution is compared using the same criteria. In the fourth evaluation, this comparison will render a better system-wise view of the proposed solution.

5.1 Location Accuracy

This section describes the evaluation of the location accuracy in the implemented solution.

Accuracy is described as the error from the measured valued to the actual true value. In order to identify this error, the deviation from the true point to the process resulting point was calculated.

Similar to the pre-mapping survey process, the true location points where marked manually in the platform triggering the Update Access Point Signals key-process. Given the extensibility of the developed platform, this evaluation data sample was obtained using the same normal process as the Update Access Point Signals, but had a special additional payload that safe-kept the true location position.

Figure C.1 illustrates the path used to perform the measurements (in red markers), the calculated point from that position (the green marker), the survey points (the blue markers), and the used survey points for the trilaterations (the orange points).

The evaluation consisted in surveying 20 points (in red markers) along a path. This path was taken from the Area 2 to the Area 1. Dividing the points in groups of 5. It started in a relatively wide and obstacle free location, passed to a highly obstacle and near the wall corridor, afterwards crossing the main lobby and doubling back this time further away from the center of the lobby. The objective of this path was to emulate a normal movement of a person going from the Cafeteria to the Library and then back to the main entrance. Because of the different types of area it passed, especially in terms of Line-of-Sight (LOS) this was considered a good emulation and data sample.

Figure 5.1: The view of the evaluated positions for the test.

Each action of marking the real position in the platform triggered the standart one second scan for the Update Access Point Signals key-process. For study purposes the surveyor would be still in that second until the confirmation of the operation-end. After twenty positions were scanned the output log was retrieved and became the sample data for the upcoming evaluations.

The obtain results of several tests/situations as described in Annex C, suggest a mean accuracy error of 7 meter is achieved, as seen in Table C.1.

Position	Error (meters)
Average	7,03
Maximum	12,84
Minimum	4,66
Standard Deviation	2,62

Table 5.1: The median accuracy retrieved evaluation values.

The average of 7 meters is higher than the expected considering the state of the art [15]. Nevertheless, to find a room it its considered an acceptable error for the IST-TP building. In the building the rooms have a pair door placement, and squared-space room disposition. This disposition creates and almost 2-room-sized distance between non paired doors. As such, even if an 12 meter error occurs when the client wants to know where he is, the displayed layout should be significantly different for him to identify his position, lowering the impact of the error margin.

Having 12 meter as the worst error may be a problem, this is likely to have happened because the points suffer from instantaneous signal reflection. Given that the survey nodes are aligned with the walls of the rooms, the NNTP approach expects for this kind of errors to dissipate when closer to the room/closer to the survey nodes.

As explained earlier, the NNTP algorithm calculates the similarity of surveyed nodes with the current unknown point and renders the Trilateration position estimation based on the similarity. Since the usage of all nodes is not viable, as seen in Appendix A, only a subset of nodes is used for the trilateration, the most similar subset. Calculating the similarities between the surveyed nodes and the unknown point, the subset is created. This subset is ordered in descending value of similarity, and the Trilateration is made with the most similar N nodes.

To evaluate and determine the optimum number of nodes, different amount of points were considered and evaluated as depicted in Table 5.2.

Position in the Map	N=3	N=4	N=5	N=6	N=7	N=8	N=9	N=10	N=ALL
-10.1263099801.-82.9663086869	3,25	4,35	5,03	6,48	4,53	6,05	6,71	8,44	25.18
-11.3352374034.-75.5834961869	10,04	10,89	10,93	10,01	8,99	8,12	6,44	5,02	15.82
-7.35459756952.-72.5964355934	8,01	8,16	5,47	5,89	5,36	5,88	6,14	5,73	15.28
-5.08304078303.-69.5202637184	6,37	2,98	4,66	5,35	5,94	5,96	5,15	4,39	11.68
-8.83381068069.-67.1472168434	9,50	10,24	6,26	8,79	9,68	8,05	6,82	6,86	7.72
-12.3751781685.-65.5651855934	11,07	11,22	8,11	7,90	8,27	8,23	7,79	8,06	9.49
-15.1917288242.-62.2253418434	13,96	12,26	9,82	10,14	10,11	10,85	9,59	8,57	10.01
-13.1466494906.-57.6550293434	9,63	9,64	11,41	12,83	11,57	12,14	11,49	11,21	6.83
-11.3430171688.-54.1394043434	4,95	6,45	8,92	9,96	10,85	12,02	13,25	13,83	9.59
-7.44175651921.-51.6784668434	8,60	7,22	7,05	7,08	6,13	7,45	7,86	8,38	6.18
-2.89122818147.-49.2175293434	9,90	7,06	4,98	4,80	4,28	2,46	3,57	2,71	10.31
3.60906126337.-44.9987793434	8,98	5,90	3,38	2,71	1,64	3,78	1,90	3,58	13.68
7.3703360219.-41.8347168434	7,35	7,05	6,85	6,66	4,86	5,15	5,14	4,77	16.99
10.3227255976.-38.0554199684	3,97	5,77	5,18	5,38	5,96	7,55	6,13	5,85	22.47
13.4187121884.-27.5964355934	12,76	14,53	12,84	14,41	14,64	15,37	16,10	16,57	35.38
9.80349645423.-28.1237793434	11,05	8,18	7,16	11,12	11,57	9,85	11,31	12,48	32.48
5.53640820886.-30.5847168434	6,42	4,62	4,63	6,38	3,97	3.29	7,31	8,44	25.54
0.886805485741.-33.5729980934	7,72	5,42	4,73	4,24	3,57	3,80	4,04	5,21	24.01
-1.66175420911.-34.6276855934	9,91	10,11	8,21	8,97	8,82	7,93	7,59	8,40	23.47
-3.76864185907.-34.1003418434	4,67	3,63	5,09	3,91	3,59	5,70	4,58	5,65	20.05
Average	8,40	7,78	7,03	7,65	7,31	7,51	7,45	7,71	17.11

Table 5.2: The median values of all the errors calculated with different Top-N nodes.

In Appendix A there is a visual representation of the calculations for each number of nodes. It is easy to visually understand that not all nodes can contribute to the trilateration/eclidean distance, as seen in *Using all nodes*. By allowing all the nodes to contribute, the Trilateration will always converse to the center of the surveyed area.

As Table 5.2 suggests, using five nodes to trilaterate the position renders the best median result in terms of accuracy with a 7.05 meters and a worst case of 12 meters.

There is a visible augmentation of error in specific points. These points are characterized by the low LOS and high reflection areas.

For the first part of Area 2, the first five point have a low error. The second part of Area 2, in the corridor, the reflection/distortion effect immediately sets in resulting in higher errors, maintaining a high error ratio until the middle of the main lobby, in Area 1. This effect is due to the closeness to a wall, the nearby pillar and the proximity of the staircase. Creating lost of line of sight and allowing for signal multipath, this objects in the building contribute to this error. From the middle of the main lobby the error drops, due to the open-space, and near the wall the error rises again.

The expectation when using the NNTP was to use the measurements in the survey nodes as a way to soften the impact of reflections and distortions. By making the surveys, it was expected that they would contain the variation of the signal in the area.

These impacts are clearer now and a possible solution is to have a dynamic way to trilaterate the position. As seen in Table 5.2, certain points have lower error than the chosen number of 5 nodes. This means that in some cases the usage of more/less nodes to trilaterate can provide a lower error.

By taking into account the similarity values of the nodes to the unknown position, and using the Fuzzy Logic algorithm, a filter can be created to allow more or less nodes to Trilaterate the final position. Allowing to dynamically change the number of nodes in the Trilateration, a lower error could be achieved.

5.2 Compass Guide Accuracy

In the evaluation made, the compass guide will always render the correct orientation to the destination point. The tinkering with the device rapidly lead to finding ways where the incorrect orientation would be displayed.

By using the device in the portrait orientation, without passing the fully vertical or the fully horizontal, in the normal 45 degree angle of usage which it is designed. The device rendered the same orientation with a maximum of 5 degrees error. This error was not considered relevant in the building-space orientation.

This evaluation was made to understand the situations were the display was incorrect and two situations were found:

Landscape mode usage is not provided by the platform. The compass will not render the correct orientation because of the missing angle compensation. This should be easily fixed by the Client Visualization Module that should be informed of the landscaped mode and adjust to a pre-calculated angle the displayed compass.

Device tilting is the face-wise rotation of the device. If the device is tilted enough, the geo-magnetic compass will render different values then expected, and will inform the platform of wrong base-geo-magnetic values. This happens when the device is at a almost vertical position or at a almost horizontal position. Passing these positions will also point the device to retrieve a different geo-magnetic orientation and thus render faulty guidance. This can be fixed, if the gyroscope information is added to the platform in order to understand how the device currently is placed. There is little gain in this, as the discussed angles do not allow for a easy usage of the device itself.

5.3 Solution Evaluation

This section describes an evaluation of the solution in terms of the system.

Similar to the evaluation made in the context of the state of the art for systems, this evaluation points to the same concepts for analyses.

Accuracy is the most important requirement of positioning systems. With a median error of 7.05 meters, this is somewhat more than expected by the state of art where the accuracy was from 3-5 meters, but can it is a good median error to identify rooms in a building.

Precision only considers the value of mean distance errors. Because of the NNTP algorithm, independently of the number of rounds taken, if the sample is the same, the result will be the same, rendering a 100% precision.

Techniques used in the NNTP algorithm was a hybrid between the RSS and Radio Fingerprinting. This allowed for a simpler implementation because the physical positioning of the access points is not required / needs to be accounted for and the required survey is lesser than the common grid-pre-mapping fingerprinting techniques.

Cost of a positioning system may depend on many factors. Since the implemented platform has a strong ubiquitous orientation, uses commonly deployed technologies, the only real cost for implementing it is the pre-mapping of points and the adjustment of the map for the clients visualization.

Availability of a platform is bound to the deployment and ease of acquisition or utilization for this technology. The implemented solution has very few requirements for its deployment and usage in client side, and in such it offers added value for a using client where the IndoorPositionr Platform is already deployed (since the only requirement is the download/running of the Client IndooPositionr).

Considering the state of the art studied platforms and systems, the IndoorPositionr has a good overall with a needed-to-be-enhanced accuracy. The proposed platform has a high Availability provided by the ubiquitous interface and the Android application. This easily allows for a new user to access the platform services. The low cost of the platform can be interpreted as well in the client-side. A client only requires a regular Android smartphone in order start using the platform.

The usage of both Techniques proved a challenge but allowed to lower the costs of implementation drastically. Even if the rendered accuracy is not as good as predicted, there is room to enhance it with the identified key problems.

5.4 Evaluation Conclusion

The location accuracy for the tested path had an outcome of a median 7.05 meters which was a good value for positioning in a room-wise scale in the IST-TP building. This evaluation also allowed to test for the best number of nodes for the NNTP algorithm rendering a usage of 5 nodes in the positioning calculations.

The evaluation of the NNTP allowed to understand the existence of areas where the impact of signal interference takes place. Namely the corridor areas and reflective areas such as near the building walls or pilars. Perceiving the different results from the various nodes used in the trilateration, some adjustments could be made to the NNTP algorithm. These adjustments would take into account the similarity of the node, and decide the best number of nodes used in the trilateration process.

The compass guide worked without problems in the platform-view, although some misuse can provide faulty orientation. These problem rely on the tilting of the device and the usage of landscape mode. The tilting of the device is a problem when outside of the 45 degree angle of normal usage, but can be compensated for special uses using the gyroscope. The landscape usage should not be complicated to accommodate, and happens because the platform is not aware of the change from portrait to landscape mode.

The solution evaluation, similar to the evaluation done to the state of the art systems, provided for a positive outcome of the proposed system because of its ease of deployment, low cost and high features ratio and a non probabilist algorithm that always renders the same position. The only downfall is the high maximum error provided in the accuracy.

In the overall the implemented solution is a stable, low-demanding and with high features and extensibility platform.

6

Conclusions

Contents

Due to the various topics, fields and overall extent of this dissertation, the conclusion has a paragraph dedicated to each major section. Starting in the State of the art followed by the Proposed Solution, the Implemented Location Solution discussion and the results. Afterwords the future work is presented.

State of the art

The state of the art chapter allowed for the understanding of current techniques and technologies used in Geo-Location systems. The emphases of the study was funnelled in to the technologies and systems that allowed indoor position location.

Understanding the gap between current Geo-Location Systems (GLS) and their use for indoor locations makes a clearer point into the room and opportunity of this dissertation. The main problems with Indoor Positioning systems (IPS) is the Non Line-of-Sight (NLOS) and technology deployment.

Studied technologies such as GPS and CN have a well matured implementation and are commonly used for positioning, but can not work indoors properly. GPS has a NLOS problem that prevents it from being used indoors, and CN costs are to high to justify the required coverage necessary for indoor environments. In the commercial area, Radio-Frequency IDentification (RFID) are wildly used, but serve as specific indoor positioning solutions which require an heavy investment. Ultra-Sound (US), and UWB are poorly disseminated technologies, and Bluetooth (BT) is too reliant on the density of devices, leaving WLAN as a good choice for an ubiquitous indoor positioning platform. Wireless Local Area Network (WLAN) was the best trade-off between technological capability, indoor deployment and common availability.

In the techniques field, the usage of multiple concepts is always present. Since Angle-Based techniques are not a standard in WLAN, and the Time-Based ones would create enormous errors for WLAN indoor location, the proposed would be an intersection between Radio Beacon and Signal Strength techniques. The three discussed algorithms were the most common for these techniques. Requiring an extensive mapping of the possible positions, the Nearest Neighbour (NN) would allow for a low calculation algorithm. With the information of the physical Access Point (AP) position, the Trilateration could be used, and without being a positioning algorithm itself, the Fuzzy Logic could be used to adjust/tune any of the discussed.

Proposed Solution

The required for this proposed solution was: the determination and visualization of position location, the guidance service and in terms of platform the ease of deployment, extensibility and ubiquity. These features should be rendered by specific modules and across the proposed platform in a clear and concise manner.

The proposed solution architecture has two abstraction layers which define the two single-entry points of communication. These points are the proposed Web API and the Indoor Positioner API. The Web API should be the communication layer that allows the platform to receive external requests using HTTP and JSON. Responsible for managing and calculating the information, the Indoor Postioner API orchestrates its internal modules to deliverer the requested service.

Providing the solutions functionality, two key-processes were defined, the Update Access Point Signals and the Request Position. The first has the role of updating position-related information from the client in the solution. The second of rendering the positioning operations from the platform.

In order to lower the implementation requirements of the solution, the hybrid algorithm NNTP uses the NN grid-alike nodes and the Trilateration pinpoint to calculate the position of a client. This positioning is used for the guidance process as the current position along with the destination position and the North position to calculate what is the angle that the client should rotate to be facing the desired location.

The proposed solution is a modular client-server based platform, which has two key-process: the positioning of a clients location through the NNTP algorithm and the retrieval and understanding of the clients surrounding information. The usage of the platform requires the visualization of the position location in a friendly and local-aware way. This will also be used by the guidance service to display the correct direction to the destination.

The proposed solution should render four core modules that are responsible for calculations of position, communications, storing of informations and interactions. This modularized implementation directly relates with the ubiquity and extensibility required, allowing for the platform to be created with clear and concise modules and accessible using the defined layers/entry-points.

Implemented Solution

The implementation of the proposed solution was an organic, iterative process. Three iterations took place allowing the used instruments to characterize the environment and evolve to the final ubiquitous indoor positioning platform, the IndoorPositionr.

The first tool, Wlanlist, allowed to notice the slow scan rate and the various informations which needed to be displayed. Visually rendering better the information and having a higher rate of scan (due to new hardware), the IndoorPositionr API was the second instrument created. The third iteration was due to the lack of mobility, ubiquity and geo-magnetic information, rendering the IndoorPositionr Platform that was used as a the final implementation of the proposed platform.

The analysis of the environment allowed to establish the five meter mark as a good trade-off between signal variation and distance between the pre-mapped surveyed nodes. The signal analysis proved to be as expected, rendering continual gain or loss while approaching or gaining distance from the broadcasting source.

The IndoorPositionr platform was build using the knowledge of the previous iterations and with a ubiquitous, easily deployable and extensible orientation. This rendered a platform highly modularized, with four core modules: The IndoorPositionr API where the positioning services are executed; the Web API responsible for the ubiquity in access and communication to the platform; the Client IndoorPositionr, a service which continually informs the platform of required data such as 802.11 signals or geo-magnetic information; and the Client Browser, where the crucial visualization and interaction for the client takes place.

The implemented platform has two key-processes, the Update Access Point Signals and the Request Position that offer the features proposed earlier. To render its featured services, the platform uses the two implemented location process, the NNTP for rendering the location of the client and the Location Guide Compass for orienting what is the direction for the desired destination. A set of rules were created along with the NNTP to accommodate error from signal interference. By taking into account the last calculated position when working in the current one, a radius of maximum range between them is inferred. This allowed for a better location positioning in the platform continuous location mode.

Results and Evaluation

The location accuracy for the tested path had an outcome of a median 7.05 meters which was a good value for positioning in a room-wise scale in the IST-TP building. This evaluation also allowed to test for the best number of nodes for the NNTP algorithm rendering a usage of 5 nodes in the positioning calculations.

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The solution evaluation, similar to the evaluation done to the state of the art systems, provided for a positive outcome of the proposed system because of its ease of deployment, low cost and high features ratio and a non probabilist algorithm that always renders the same position. The only downfall is the high maximum error provided in the accuracy.

In the overall the implemented solution is a stable, low-demanding and with high features and extensibility platform.

As stated in several places across the dissertation, there is a lack of simple indoor positioning systems, the recent launch of Google Map Indoors only strengthens this idea. Due to the lack of line-of-sight a IPS platform must used several techniques and adjustments to achieve the best results, and because of the cost of implementing new systems for each indoor location a good choice is to adapt commonly used wireless systems to track indoor locations.

The proposed solution rendered a solid, extensible and usable platform that had room to innovate by creating the NNTP algorithm in order to bring down the cost of implementation in different locations while offering promising precision and tools to enhance it.

The implemented solution is a complex tool yet offers simple usage, and allows for an easy usage and can also be easily used for building-wide indoor location. The achieved results are not as good as thought, but for a indoor locations service offer the enough precision to guide a person inside a building. This platform can easily be a basis for a big project, due to its scalability and allow services based on the user location for indoors.

In the overall this was a engineering problem with a scientifical learning experience which the outcome was, what it set out to be, a functional system that offers location for users inside a building.

6.1 Future Work

For future work, and due to the nature of the implement project a few points are discussed:

GPS Due to the platform extensibility, a GPS module can be introduces leaving room for a seamless transition from out side location systems to the IndoorPositionr Platform.

Custom Compass The compass guide can be easily extended to received custom marks from the user and begin the guidance process to that location instead of pre set locations.

Fuzzy Logic Fuzzy logic techniques can be used to better select the nodes used in the NNTP algorithm opening the possibility for better location outcome.

More Locations The platform can be expanded to include other locations/sites such as IST-Alameda.

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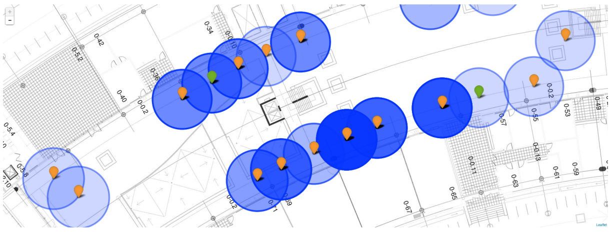
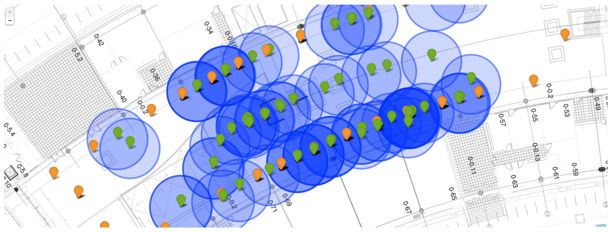
A

Appendix A

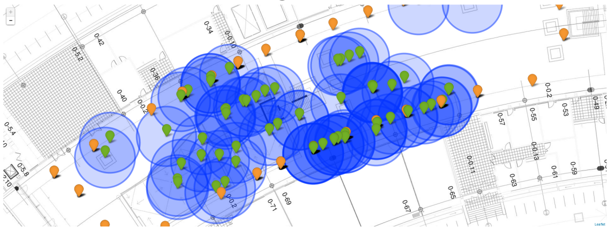
Shown below are the visualizations of the platform calculated positions for the surveyed path using from 1 to 9 nodes for the Trilateration process.



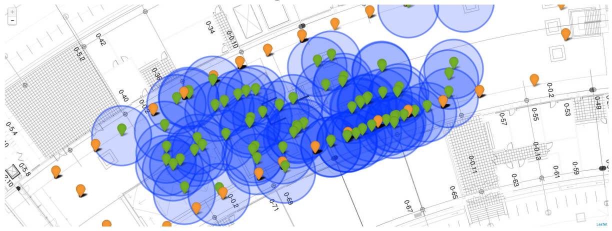
Using 1 node.



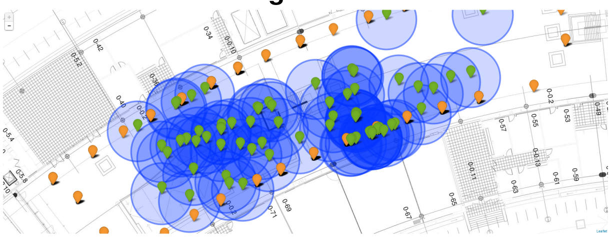
Using 2 nodes.



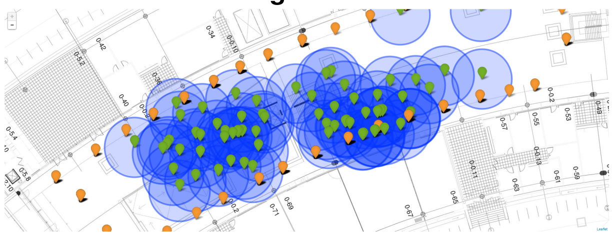
Using 3 nodes.



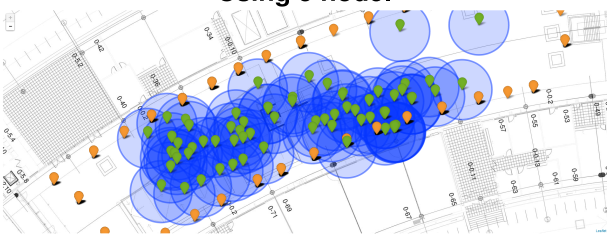
Using 4 nodes.



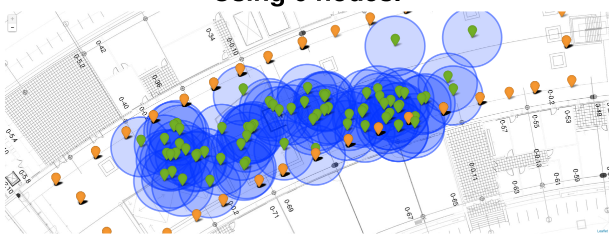
Using 5 node.



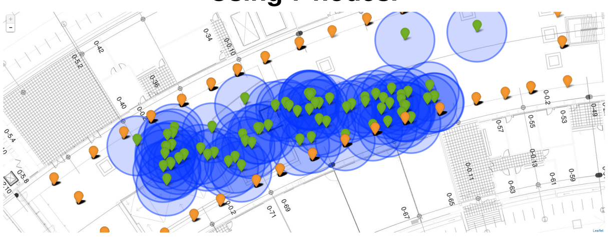
Using 6 nodes.



Using 7 nodes.



Using 8 nodes.



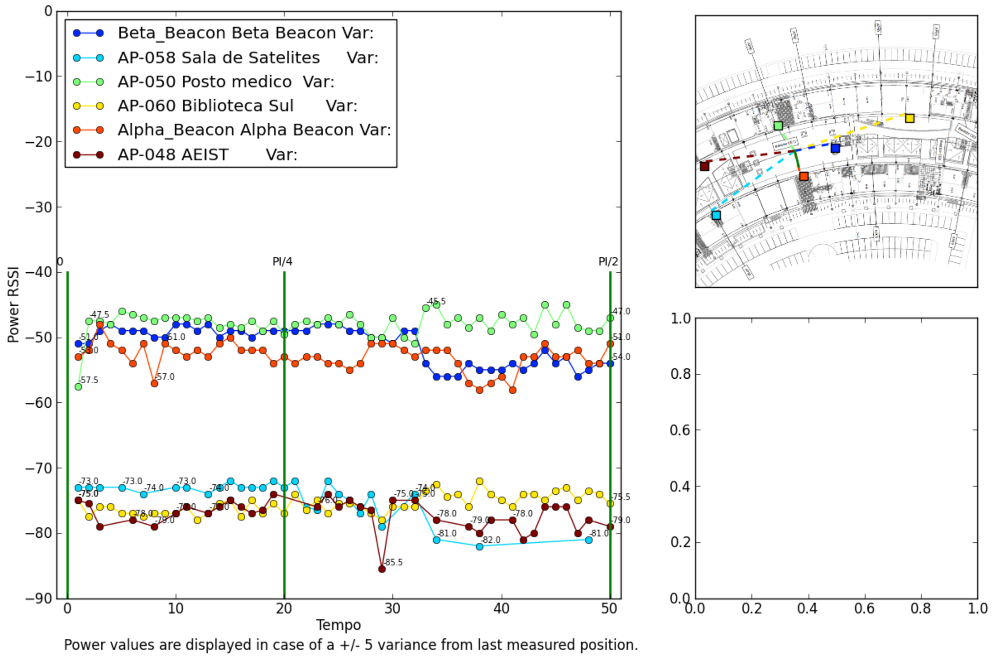
Using 9 nodes.

Using all nodes.

B

Appendix B

This is the rotation graphic, created to analyse the power received versus the angle facing the Access Point.



360

Rotation signals measurement

C

Appendix C

This annex details the evaluation of the location accuracy in the implemented solution.

Accuracy is described as the error from the measured valued to the actual true value. In order to identify this error, the deviation from the true point to the process resulting point was calculated.

Similar to the pre-mapping survey process, the true location points where marked manually in the platform which triggered the Update Access Point Signals key-process. Given the extensibility of the developed platform, this evaluation data sample was obtained using the same normal process as the Update Access Point Signals with a special additional payload that safe-kept the true location position for posterior use.

Figure C.1 illustrates the path used to perform the measurements (in red markers), the calculated point from that position (the green marker), the survey points (the blue markers), and the used survey points for the trilaterations (the orange points).

Figure C.1: The view of the evaluated positions for the test.

The evaluation consisted in surveying 20 points (in red markers) along a path. This path was taken from the Area 2 to the Area 1.

Dividing the measured points in groups of 5, it started in a relatively wide and obstacle free location, passed to a highly obstacle and near the wall corridor, afterwards crossing the main lobby and doubling back this time further away from the center of the lobby. The objective of this path was to emulate a normal movement of a person going from the Cafeteria to the Library and then back to the main entrance. Because of the different types of area it passed, especially in terms of Line-of-Sight (LOS), this was considered a good emulation and data sample.

Each action of marking the real position in the platform triggered the standard one second scan for the Update Access Point Signals key-process. For study purposes the surveyor would be still in that scan until the confirmation of the operation-end. After twenty positions were scanned the output log was retrieved and became the sample data for the upcoming evaluations.

Three situations were used as test scenarios. The first, Situation 1, was made in the described path, with a low number of persons around, in the late afternoon, taking 15 samples per point-in-path. Situation 2, was made in the same path, with a small increase of persons due to the near afternoon break hour (around 17h), and taking 15 samples also. In order to perform a more agile test, Situation 3 was made with few people in the area, at night, with 1 sample per point-in-path.

The obtained results from median of the three tests, suggest an accuracy error of 7 meter, as seen in Table C.1.

Position	Error (meters)
Average	6,4959
Maximum	14,53
Minimum	1,9
Standard Deviation	4,15

Table C.1: The accuracy retrieved from the evaluation values.

The average of 7 meters (rounded from 6.5meter) is higher than the expected considering the state of the art [15]. Nevertheless, to find a room it its considered an acceptable error for the IST-TP building. The rooms in the building are placed with the doors in a paired fashion, along with a squared-space room disposition. This disposition creates and almost 2-room-sized distance between non paired doors. As such, even if an 14 meter error occurs when the client wants to know where he is, the displayed layout should be significantly different for him to identify his position, lowering the impact of the error margin.

As explained earlier, the NNTP algorithm calculates the similarity of surveyed nodes with the current unknown point and renders the weighted Trilateration position estimation based on the similarity. Since the usage of all nodes is not viable, as seen in Appendix A where only a subset of nodes is used for the trilateration, a subset of most similar needs to be determined. Calculating the similarities between the surveyed nodes and the unknown point, the subset is created. This subset is ordered in descending value of similarity, and the Trilateration is made with the most similar N nodes.

To evaluate and determine the optimum number of nodes, different amount of points (N) were considered and evaluated. 1, 5 and 10 samples were also used in the evaluation, in order to understand the usage of multiple samples in the error. By calculating all the distance-error from all the points in the path using different N (number of nodes to trilaterate), the Figure C.2 for Situation 1 and the Figure C.3 for Situation 2 were obtained.

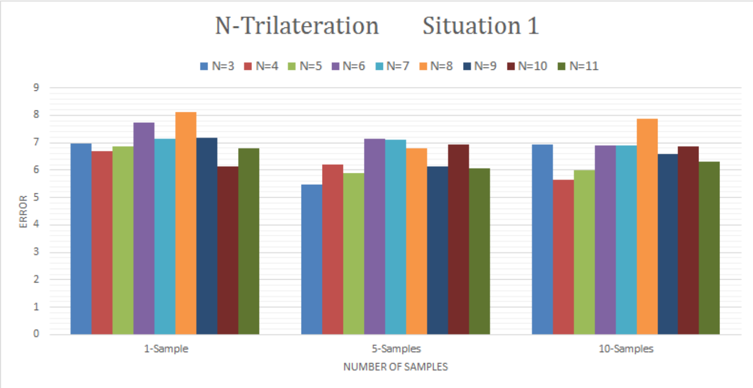


Figure C.2: The median error using different N in Situation 1 for 1, 5 and 10 samples.

In the Situation 1 both N = 4 and N = 5 have a small variation when increasing the number of samples, comparatively to the N = 10 (which had the lowest median error for 1 sample). It is also noticeable that higher N's (N = 10,11) have the second lowest median error, when looking to the data, it is understandable because the high number of points in the middle of the tested area. When using the NNTP algorithm, the more number of points used to trilaterate the more the convergence to the center of the area happens.

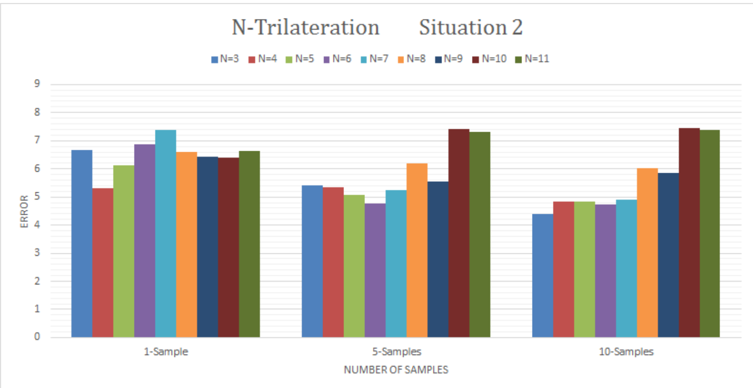


Figure C.3: The median error using different N in Situation 2 for 1, 5 and 10 samples.

In Situation 2, N = 4,5 have the lowest values across the samples, but in this case N = 3, and the middle N's, N = 6,7,8 have also low variation and low errors. The middle N's lower error and the high error on the N = 10,11 facts were investigated. This result was attributed to the quality of the samples. In this Situation, the increased number of persons at the time, increased the RSSI values (where less is better signal) from the broadcasting AP's. This resulted in a deficient contribution from AP's that are further away, and in such, made the NNTP similarity less weighted in those noses. The middle N points were benefited because the more similar nodes had a stronger RSSI and were taken into account more than the farther away nodes. The higher N points were not benefited because the deficient weight of farther nodes will contribute to a worst positioning.

As both Figure C.2 and C.3 suggest, the N = 4 and N = 5 have the lower error across the various tests/samples and situations. In order to understand the differences between them, the side by side median error was plotted, in Figure C.4, and in Figure C.5 the standard deviation was also plotted.

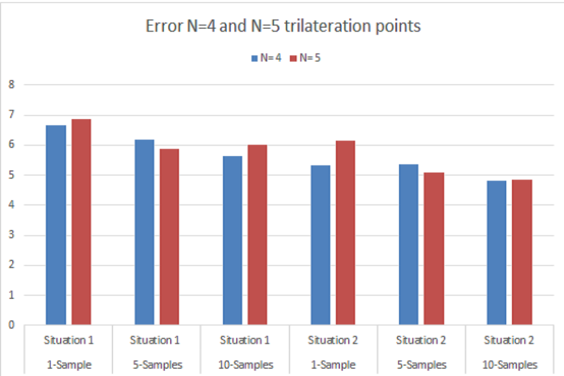


Figure C.4: The comparison of median errors for N = 4, N = 5 in Situation 1,2.

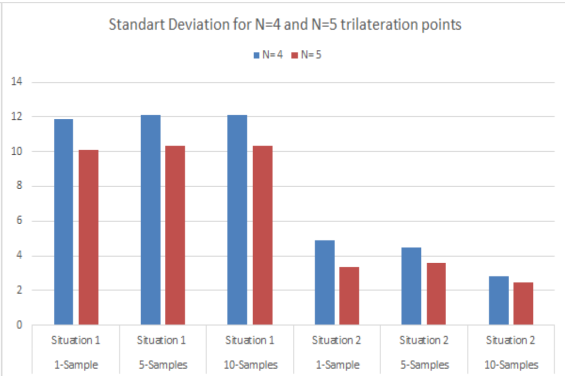


Figure C.5: The comparison of standart deviation errors for N = 4 and N = 5 in Situation 1,2.

The discussion on the usage of N = 4 or N = 5 is more defined in the standart deviation. While the median error shows that N = 4 has in average less of an error distance, the standart deviation, depicts the variation of error from the median average. This variation is always greater in the N = 4, which means that in the long run, the N = 4 will provide higher errors for the NNTP algorithm.

Taking into account a more real-world usage of the platform, the Situation 3 was created, and the measurements of error were taken using just one sample in each point-per-path. The Figure C.6 depicts this information.

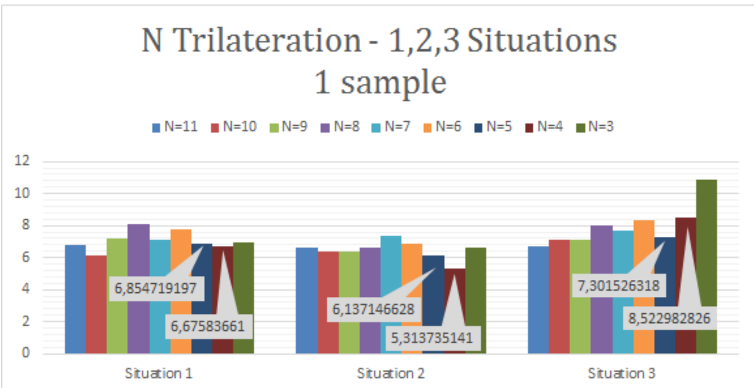


Figure C.6: The median error using different N in Situations 1,2 and 3 for 1 sample.

In the Figure C.6, the error of the N = 5 (in dark blue) had a small variation, from 6.137 meter (in Situation 2) to 7.3 meter (in Situation 3). The median error increased for almost every N values in the Situation 3 and it is visible that the high N values had a smaller variation, this is due to the conversion effect. Clearly the Situation 3 had an environment or testing procedure error. Since it was a low person Situation, it was expected that the values would not differ much from the previous Situations.

In Appendix A there is a visual representation of the calculations for each number of nodes. It is easy to visually understand that not all nodes can contribute to the trilateration/eclidean distance, as seen in *Using all nodes*. By allowing all the nodes to contribute, the Trilateration will always converse to the center of the surveyed area.

In the raw data there is a visible augmentation of error in specific points. These points are characterized by the low LOS and high reflection areas.

For the first part of Area 2, the first five point have a low error. The second part of Area 2, in the corridor, the reflection/distortion effect immediately sets in resulting in higher errors, maintaining a high error ratio until the middle of the main lobby, in Area 1. This effect is due to the closeness to a wall, the nearby pillar and the proximity of the staircase. Creating lost of line of sight and allowing for signal multipath, this objects in the building contribute to this error. From the middle of the main lobby the error drops, due to the open-space, and near the wall the error rises again.

The expectation when using the NNTP was to use the measurements in the survey nodes as a way to soften the impact of reflections and distortions. By making the surveys, it was expected that they would contain the variation of the signal in the area.

These impacts are clearer now and a possible solution is to have a dynamic way to trilaterate the position. Because certain points have lower error when the chosen a number of nodes different from 5. This means that in some cases the usage of more/less nodes to trilaterate can provide a lower error.

By taking into account the similarity values of the nodes to the unknown position, and using the Fuzzy Logic algorithm, a filter can be created to allow more or less nodes to Trilaterate the final position. Allowing to dynamically change the number of nodes in the Trilateration, a lower error could be achieved.