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Indoor Location-Based Services In The Telecommunications Network

Master's Thesis submitted in partial fulfillment of the degree of Master of Science in Technology

Espoo, July, 2014

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AALTO UNIVERSITY **ABSTRACT OF THE MASTER'S THESIS**

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Title of the Thesis:	Indoor Location-Based Services In The Telecom Network
Date:	July 30, 2014 **Number of pages:** 68
Department:	Department of Communications and Networking
Professorship:	Radio Communications
Supervisor:	Jyri Hämäläinen, Professor, D.Sc.
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'Location-based services' are services that take the location of mobile devices into account. Traditionally, these services have revolved around positioning and navigation. However, with the advent of smartphones equipped with GPS receivers, a number of innovative location-based services have come into the market and caught users' interest.

Users spend nearly 90% of their time indoors and GPS receivers do not function well within buildings. Hence, there is a need for a reliable indoor positioning system. Alongside technological research, a study of indoor location-based services is also necessary.

'Open Telco' refers to the endeavour by mobile operators to follow in the footsteps of internet companies and embrace open innovation and open APIs (Application Programming Interfaces). Network service exposure and the ecosystem approach are believed to be critical to the future success of mobile operators.

This Thesis attempts to bring together these three dissimilar but related topics- indoor positioning, location-based services and network service exposure. This is done via the study of existing literature and the implementation of a service prototype.

Keywords: *Indoor Positioning, Location-Based Services,Service Exposure, Maps, Network APIs, Open Telco.*

Acknowledgments

This Thesis is the result of the contributions of several individuals, to whom I am grateful.

First and foremost, I thank my thesis supervisor Professor Jyri Hämäläinen for his ready guidance and insightful inputs throughout the course of theis Thesis. Secondly, thanks go out to my instructor Raul Söderström for giving me the opportunity to work with the wonderful people from the New Business Development team at Ericsson, Finland and for giving me a nudge in the right direction whenever the Thesis did not move forward, which happenned often.

I would also like to individually thank the entire In-Call team and my friends from NomadicLab for their support and guidance – Emil, Markku, Peter, Kaushik, Juan, Kenneth, Tuomas, Jaime and Aimmy. They were with me the entire way and never let me lose sight of my goal. My sincere gratitude goes to Ella for her forthcoming help with the user tests.

Ville and Teemu also played an invaluable role with their contributions to EricsPoint. It was an enriching experience to work with them. I am also grateful to Pradeep, Vasuki, Anil and Jaikar for reviewing the text.

I especially appreciate the work of the developers and designers of Android, Googledocs, Bitbucket, Dropbox, Evernote and Microsoft Office. Your work has helped me and thousands of students immensely. May God bless you all!

Finally, I thank the people in my life, family and friends, for all the smiles, laughter and happiness. You have all been very nice to me!

Jorvas, June 2014

Arjun P. Kamath

To Aanu & Amma

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ABBREVIATIONS

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
AP	Access Point
AS	Application Server
CN	Core Network
CSCF	Call Session Control Function
EDGE	Enhanced Data rates for GSM Evolution
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
HLR	Home Location Register
HSS	Home Subscriber Server
ICT	Information and Communication Technology
IMS	IP Multimedia Subsystem
IP	Internet Protocol
ISP	Internet Service Provider
ITU	International Telecommunication Union
LAN	Self - Organizing Network
LBS	Location-Based Service
LoS	Line-of-Sight
LTE	Long Term Evolution
MRFC	Media Resource Function Controller
MRFP	Media Resource Function Processor
OTT	Over The Top
QoS	Quality of Service
RAT	Radio Access Technology
RCS	Rich Communications Services
RFID	Radio Frequency Identifier

RNC	Radio Network Controller
RP	Reference Point
SDK	Software Development Kit
SDS	Service Development Studio
UE	User Equipment
URI	Uniform Resource Identifier
UWB	Ultra Wide Band
WAP	Wi - Fi Access Point
WCDMA	Wideband Code Division Multiple Access
WiFi	Wireless Fidelity

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Chapter 1

INTRODUCTION

Over the past few decades, advancements in the fields of telecommunications and transport have turned the world into a global village. It is now possible to instantly speak to anyone anywhere with a mobile phone. Similarly, there has been an increase in global trade and travel across countries and continents. Thus the ability to position and navigate people and goods has become critical.

The most widely used positioning services of today are based on the Global Positioning System (GPS). These services are usually limited to outdoor positioning and navigation using a visual map interface. However, users spend nearly 90% of their time indoors [1]. So there is a large demand for positioning and location-based services within buildings and homes. GPS-based services cannot be used indoors since satellite radio signals cannot pass through building walls [2]. Hence there is a need for an indoor positioning system to complement GPS.

Several technologies and approaches have been proposed and used for developing indoor positioning systems. Triangulation and trilateration use ‘signal strength to distance conversion’ to approximate the user’s location, while fingerprinting, though simpler to implement, requires an offline phase to create a radio map of the location [3].

The technology needed to build indoor positioning systems already exists [2]. However these systems and their related services are yet to enter the market in a wholesome and comprehensive manner due to lack of standardization and operator support, incompatible base-technologies, accuracy-to-application mismatches, need for dedicated local infrastructure and the like.

It is highly unlikely that a standard indoor positioning system based on a single technology will emerge in the near future [2]. Hence it is argued that, rather than trying to develop a standard technology, it would be prudent to design a framework abstracted from the base-technology and algorithms [4]. Such a framework would bring together wireless technologies and position estimation algorithms thus enabling the speedy development of indoor positioning applications.

Location-based services (LBS) can and should be about more than just positioning and navigation. A user's location is a powerful indicator of his/her context and could be used to develop a much wider variety of services.

A major category of location-based services is location-aware telephony. Communication decisions can be made based on location information, for example, disabling instant messaging and automatically redirecting calls to voicemail while driving. Location information can also be used to trigger communication actions such as setting the phone to vibrate mode when in a movie theatre or sending an automated SMS to one's spouse when leaving then office. Additionally, location-aware telephony can be used to deliver relevant information to the user, for example, an SMS listing the coffee shops nearby or a reminder phone call when passing by a gas station.

A precondition for such services would be that the particular location-based service running in the telecom network has access to the user's location as well as information about the call. This could be a standalone application having access to the necessary information. However, another solution that has been proven to spur new and innovative applications [5] [6] is to expose network information and capabilities through open APIs (Application Programming Interfaces) in a concept referred to as Open Telco. This will enable external developers to build applications on top of voice and messaging that also take into account user's location. If implemented through well defined, easy-to-use and secure APIs, this would be highly valuable for operators. Developers can use these APIs for novel service creation, thereby adding value to operators' existing network deployments and enabling them to compete with Over The Top (OTT) competitors with location-aware telephony [5]. Consumers will benefit from a wide range of services to choose from and developers will profit from selling those services.

Similarly, operator support and the high-volumes of potential customers that accompany it would enable economic network-based location information. This would in turn enable the Long Tail of location-based services [4] [7].

1.1. **Research Objectives**

The research objectives of this Thesis are as follows:

1) Conduct a literature study on existing indoor positioning techniques and location-based services.
2) Develop a fully functional indoor positioning system based on a suitable technique.
3) Build an indoor positioning service prototype using the 3GPP core network and evaluate it from users' perspective.

1.2.**Scope of the Thesis**

The indoor positioning system was developed from scratch since there were no open source alternatives available with sufficient support. Although this approach was time consuming, it resulted in an intuitive understanding of both the system as well as the WiFi fingerprinting technique. Such intuitive understanding proved to be extremely useful in building the service prototypes.

The concept of network service exposure was explored and utilized to build a service prototype. To implement service exposure in the prototype, the Ameche platform was used. Ameche (developed by Tropo Inc.) [8] is an example of a platform that exposes network capabilities from the signaling and media plane. Ameche, which is essentially an IMS (IP Multimedia Subsystem) Application server, enables the deployment of applications within a call using whispers, announcements, call recording, conferencing and IVR (Interactive Voice Response) that can be further integrated with web services.

The scope of this Thesis provided a unique opportunity to explore a majority of the steps that are typically involved in the development a new service. A service typically requires an ideation process, an evaluation of existing related services, conceptualization, development of the underlying technology, speculation of economic and business value, building of a prototype(s) and performing user tests followed by commercialization and improvements based on feedback [9].

An earnest attempt was made to consider each of these steps. This approach, however, broadened the scope of the content. Only the technicalities of the indoor positioning system that was developed are described in detail.

1.3. Outline of the Thesis

The Thesis is structured in the following way:

Chapter 2 briefly introduces the three core concepts brought together in this Thesis. The principles behind the most common indoor positioning techniques are first described. Special importance is given to WiFi fingerprinting. The other two concepts, namely location-based services and service exposure are then presented.

Chapter 3 describes in detail the prototype indoor positioning system that was built during the course of this Thesis. This is followed by an analysis of location-based services and service exposure, based on literature study and investigations.

Chapter 4 focusses on the two services prototypes, 'Friend Finder' and 'Exhibition Helper' that were developed to demonstrate the research findings of this Thesis.

Chapter 5 discusses the user tests that were conducted to gauge user interest on the 'Friend Finder' service prototype. The results of these tests are presented in the form of a SWOT analysis.

Finally, Chapter 6 concludes this Thesis. It also discusses the scope for future research in this area.

Chapter 2

INDOOR POSITIONING TECHNOLOGIES & LOCATION-BASED SERVICES

This chapter briefly describes the techniques and theories that were studied as part of this Thesis. Firstly, various indoor positioning techniques are described. Special emphasis is laid on WiFi fingerprinting. This is followed by a brief description of location-based services. Lastly, the concept of service exposure in the telecom network is touched upon with stress on its need and related challenges.

2.1. **Indoor Positioning Techniques**

Indoor positioning has been a widely studied research area for many years now [2] [3]. As a service however, the use of indoor positioning systems has not become as widespread as GPS-based outdoor positioning systems.

The present-day smartphone is equipped with several sensors that can be used in positioning. These include: WiFi & Bluetooth sensors, accelerometer, gyroscope, GPS receiver, air pressure sensor and magnetometer [10]. Most indoor positioning techniques utilize the device's wireless antennae, sometimes in conjunction with other sensors. As WiFi access points (APs) are widely deployed in several public places, indoor positioning solutions often choose WiFi as the base technology.

WiFi based positioning systems can be broadly classified on the basis of the underlying technique [2] [3] [11] [12]. The three broad categories are:

- Proximity sensing
- Triangulation
- Fingerprinting

Positioning systems can also be divided into terminal-based (or self-positioning) systems (see Figure 2.1) and network-based (or distributed positioning) systems (see Figure 2.2). This categorization is based on whether the position of the mobile device is estimated at the terminal or in the back-end network [13]. GPS is terminal-based.

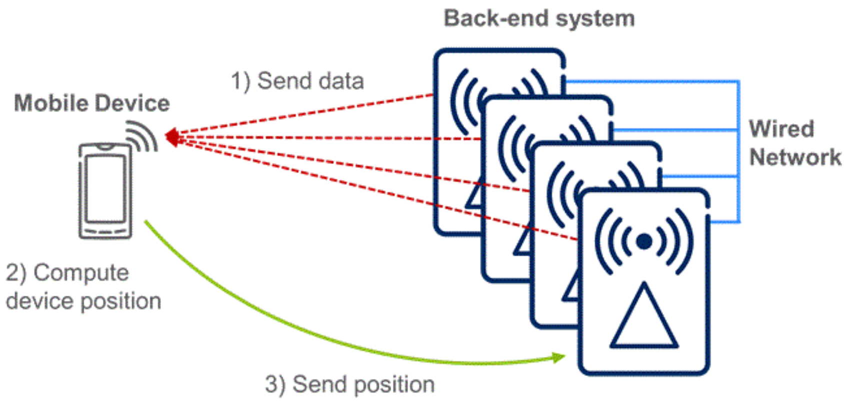


Figure 2.1: Terminal-Based positioning system

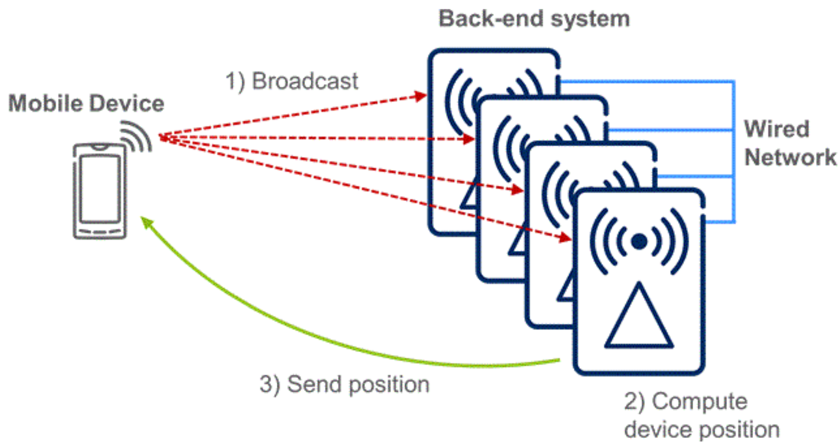


Figure 2.2: Network-Based positioning system

2.1.1. **Promixity sensing**

This is the simplest positioning technique. The principle is that when the signals transmitted by an object are detected by a receiver antenna, the object is said to be located somewhere in the receiver's range [11]. When detected by multiple receiver antennae, the one that detects the strongest signal is chosen. Clearly positioning based on proximity sensing is network-based.

For example, in Figure 2.3 device A is detected only by AP3. Therefore it is said to lie in the pink circle. Device B is detected by both AP1 and AP2. However, being nearer to AP1, the RSS at AP1 from device B is higher than that at AP2. Hence device B's location is said to lie in the blue circle.

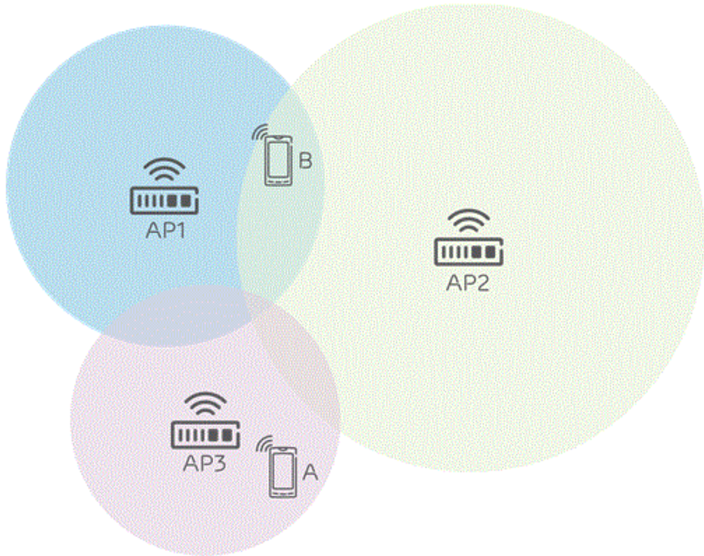


Figure 2.3: Positioning based on Proximity sensing

Obviously, the accuracy of this system depends on the density of the antennae and maximum signal range. Positioning systems based on infrared radiation (IR) and radio frequency identification (RFID) typically utilize this technique. Knowledge of the Cell-ID in cellular networks thus gives an approximate location of the mobile device.

2.1.2. **Triangulation**

Positioning systems based on triangulation utilize known coordinates of APs (transmitters) and trigonometry to determine the location of a mobile device. Triangulation is classified as a network-based as the device's position is estimated in the network, even though data is often sent in both directions (network to device and vice versa). Triangulation has two derivatives- lateration and angulation.

A) Lateration

The basis of lateration lies in finding the radial distance between the mobile device and APs. By using this information together with the coordinates of APs, the location of the mobile device can be deduced. The radial distance between an AP and the mobile device can be estimated in several ways.

Time of Arrival (TOA)

WiFi signals are electromagnetic waves that travel with the speed of light. Thus, if the propagation time between an AP and the mobile device is known, the distance between them can be determined [14]. To illustrate, in Figure 2.4 if only the distance 'R1' from AP 'A' is known, the mobile device could lie anywhere on the green circle. If 'R2' from AP 'B' is also known, the device could lie on either of the 2 points where the green and brown circles intersect. Thus the actual position 'P' of the mobile device can be determined, if its distance 'R3' from a third AP 'C' is also known.

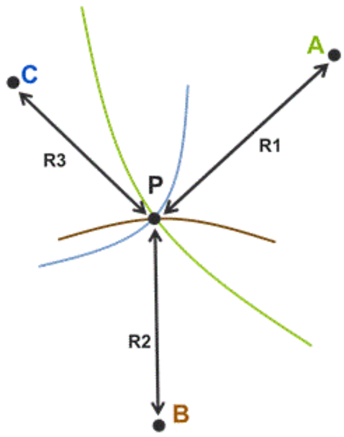


Figure 2.4: Time of Arrival based positioning

In TOA-based systems, the one way propagation time between the device and AP is needed. The main challenge is the need for accurate time synchronization and measurement.

Time Difference of Arrival (TDOA)

The basic idea in TDOA-based system is determining the relative distance between the mobile device (transmitter) at P and APs (receivers) at A, B and C (Figure 2.5). This is done by measuring the difference in time at which the signal arrives at the receiver. Each TDOA measurement gives a hyperboloid where the transmitter could lie. In a 2-dimensional area the position of the mobile device can then be calculated using two independent TDOA measurements [14].

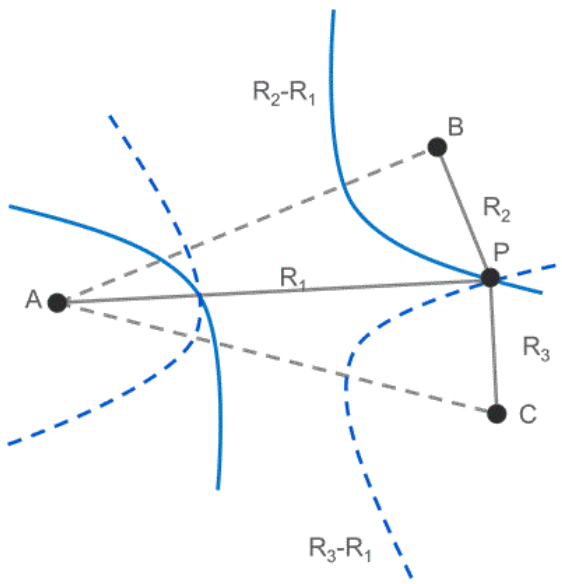


Figure 2.5: Time Difference of Arrival based positioning

Signal propagation model

Both TOA and TDOA based techniques face severe drawbacks in an indoor environment due to multipath and rarity of direct Line of sight (LOS) between the transmitter and receiver. An alternative approach is to estimate distance by measuring signal attenuation at the receiver [15]. Indoor path loss models are used to correlate signal attenuation and distance [16] [17] [18]. Thus by measuring the path loss at a receiver from at least three transmitters as shown in Figure 2.6, the position of the receiver can be calculated.

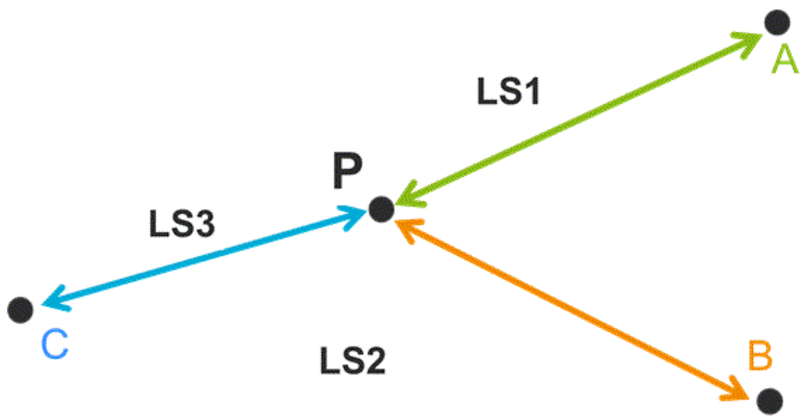


Figure 2.6: Positioning based on signal propagation model, where LS1, LS2 and LS3 denote the measured path loss

The challenge with this technique is that path loss models do not hold well in indoor environments due to shadowing and multipath fading. Thus the models need to be site specific and needs to be updated.

Received signal phase

In this technique, the carrier phase or phase difference is used to estimate distance to the receiver [3]. This technique is only usable when the maximum distance to the receiver is less than the signal wavelength. Distance can be calculated by measuring the phase of the received signal at the receiver R as shown in Figure 2.7. Using this information along with the positions of the transmitters A, B, C and D, the target's position can be determined as shown in Figure 2.8

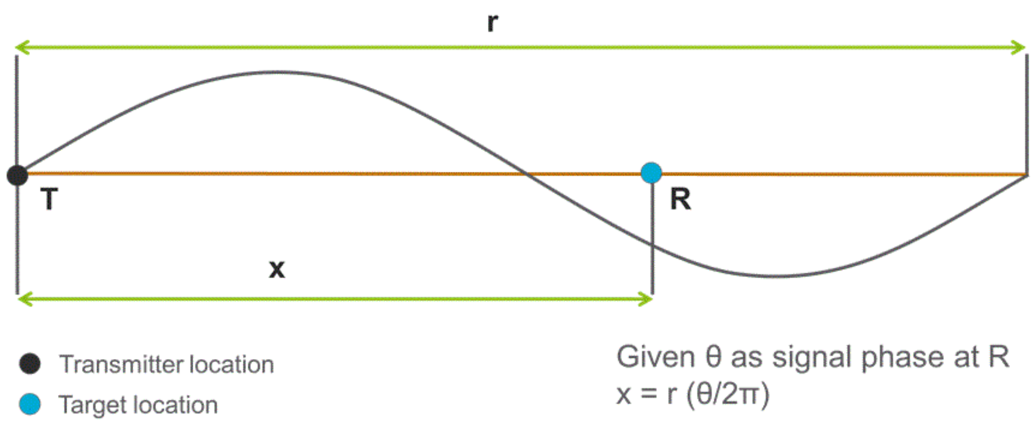


Figure 2.7: Determining distance to target using signal phase

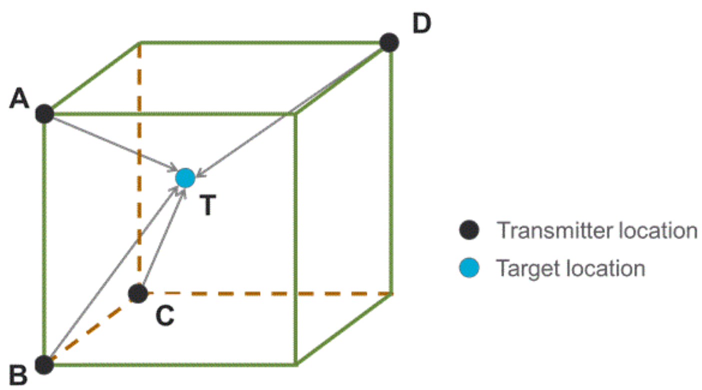


Figure 2.8: Positioning based on received signal phase

B) Angulation

Also known as AOA or Angle of Arrival technique, this method requires directional antennae or an array of antennae. The 2–dimensional position of a device with respect to the known location of two reference points (A and B) can be determined from the measured angle to the mobile device (Figure 2.9) [11].

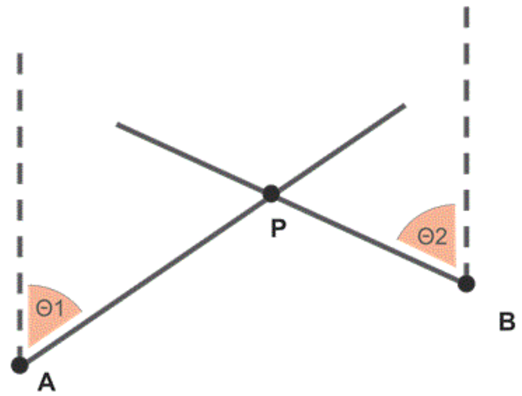


Figure 2.9: Positioning based on Angle of Arrival

2.1.3. **Fingerprinting**

Both Triangulation and proximity based techniques require prior knowledge of the location of APs, while fingerprinting does not. The basic underlying principle of fingerprinting is that the received signal strength (RSS) values detected at a point from various APs is stable in time and unique in space. Fingerprinting can be implemented as either terminal-based or network-based depending on where the position estimate is calculated.

This technique is divided into two phases, fingerprinting phase and positioning phase. During the fingerprinting phase, a radio map is created by collecting and storing RSS readings from stationary wireless transmitters, known as access points or APs at known positions in the physical environment, known as reference points (RPs). These readings are called fingerprints, as they serve to uniquely identify each particular RP.

Once the radio map is constructed, positioning can take place. At an unknown position, RSS readings are taken and compared with the stored fingerprints using pattern recognition algorithms. Thus, this technique involves reverse-mapping RSS-readings to a location by comparing the current unknown RSS environment to the saved environment via fingerprints [11].

The indoor positioning system developed as part of this Thesis is based on a network-based WiFi fingerprinting technique. In several papers, the fingerprinting and positioning phases are referred to as offline/training/calibration phase and online phase respectively.

2.1.4. Challenges in RSS-based positioning & why WiFi fingerprinting was chosen

The unpredictable variation of RSS in the indoor environment is the major technical challenge for RSS-based WiFi positioning systems [19].

These variations occur due to four main reasons. Firstly, due to the closely-spaced structures in the indoor environment and the presence of obstacles, such as walls and doors, WiFi signals experience severe multi-path and fading and the RSS values at a particular position varies over time. Secondly, WiFi uses the 2.4 GHz license-free frequency band which is also used by other devices such as cordless phones, Bluetooth devices and microwaves, leading to heavy interference. The third main reason is that WiFi operates in the 2.4GHz frequency range and radiation in this range is readily absorbed by water. This results in strong attenuation of WiFi signals by human bodies, which contain large quantities of water. Finally, the orientation of the measuring device also affects the RSS readings, as the transmitted signals are not isotropic in real indoor environment [20]. As a result, it is difficult to obtain a reliable radio propagation model to describe the RSS-to-distance relationship.

On the other hand, fingerprinting is based on comparison of empirically observed RSS values and does not depend on any theoretical models. Accuracy of nearly 3 metres can be obtained, depending on the density of APs in the test area and the number of fingerprints taken during calibration. Thus, even though it requires pre-made measurements in the test area, fingerprinting is a favoured and widely used technique in many commercial indoor positioning systems today [4].

2.1.5. **Advantages of fingerprinting**

The only pre-requisite for WiFi fingerprinting is that WiFi APs are installed beforehand and remain stationary when the system is operational. In most urban and suburban environments today, 802.11 WiFi APs are already installed. Also, there is no need to even connect to any of these APs. Hence a fingerprinting-based indoor positioning system requires only software implementation and does not necessitate installation of any new wireless hardware.

In fingerprinting, the set of RSS values received at a particular point in space is associated with a location identifier. Usually this identifier is the Cartesian coordinates of the point on a map, for example the latitude and longitude of a point on the earth. This identifier could also be a photograph taken at that position or the name of that position/nearest landmark in textual form.

If the APs are moved or new ones are added later, fingerprinting has to be re-done. No additional steps are needed. The map used in a fingerprinting-based positioning system does not have to be the actual scaled map. The map is essentially a means for the fingerprinter to tell the user what is known about the position. This makes fingerprinting especially conducive to building location-based services.

2.2. **Location-Based services**

Location-Based Services or LBS in short, are mobile services that take into account the location of mobile devices. Due to the cheap availability of GPS receivers, navigation and mapping outdoors has become quite accessible, especially to smartphone users.

By integrating (geographic) location into services, additional value can be provided to the user. Hence, there has been an increase in the popularity and importance of LBS in the mobile device market. Examples of widely used commercial location-based services are Google maps, Nokia City Lens and Yelp. Location sharing services such as Foursquare, Gowalla (acquired by facebook) and Google Latitude are popular as well.

However, it has been concluded in [21] that locating users is no longer a service by itself. Existing services can be improved and new services can be developed, if user’s location information is available. Thus, some literature speaks of the concept of location as an enabler instead of the term Location-Based Services.

Conventionally, location-based services are thought to revolve mainly around tracking and navigation-like applications. A user's location in the form of coordinates relative to a map i.e. geospatial coordinates such as latitude, longitude and altitude on the world map or local coordinates on an indoor map, can be used to track and navigate him/her in real-time.

Other than navigation, these absolute coordinates are quite unusable for building additional location-based services, unless complemented with additional local, temporal or contextual information. Services need to have an understanding of the user's context to be able to provide value.

User's location can be an indicator of his/her context. But this depends on how location is described. For example in Figure 2.10, the user's location can be described as coordinates relative to the map, '35, 10' or the address of the room, 'H4' or the name of the room 'Server Room'. Though each form of location information refers to the same position, the name of the room makes the user's context immediately apparent.

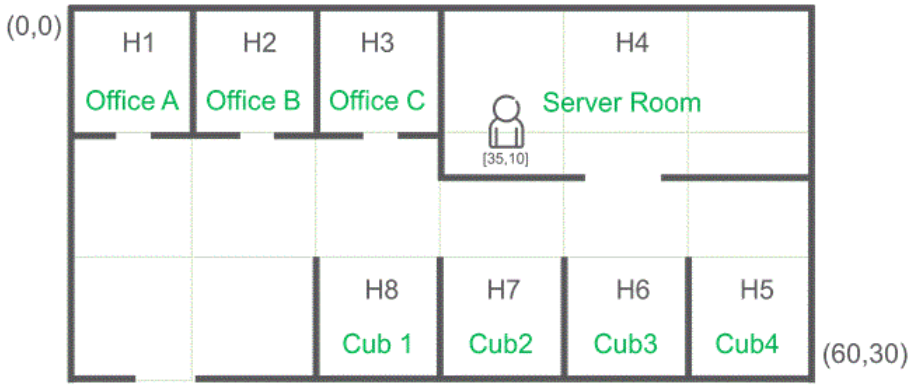


Figure 2.10: Location and context

2.2.1. **Location in Telecom**

Telecommunications services can be greatly enhanced if they are made location-aware. For example, locating the called party, being informed of the time-zone of the called party or office calls going to voicemail when at home. However unfortunately, even though operators (running GSM, WCDMA, LTE networks) have access to the user's location information [22], it is not exploited to build or enhance services.

Telecommunications network capabilities and location-based services can be mutually beneficial to one another. As described before, telephony services such as voice and SMS could be greatly enhanced by taking into account the user's location. In a similar way, telephony and text messaging services can act as means to deliver location-based services, and therefore benefit the entire location-based services industry. For example, SMS listing nearby restaurants or getting a call when passing by a grocery store on the way home.

2.2.2. **Need for abstraction**

Several aspects of the technology behind positioning, both outdoor and indoor, have either developed and matured, like GPS, or are rapidly developing. Examples of the latter are WiFi and Bluetooth based fingerprinting [23] [24], positioning using magnetometers [25], accelerometers [26], infrastructucture systems like floor tiles and lamps [27] [28].

However, location-based services should be examined from the end-user standpoint rather than the technology perspective. What matters to end-users is how well the service works and and how much it improves their lives. Most users are agnostic to the technology behind the service [29]. Hence in this Thesis, the discussions on LBS will focus primarily on the application layer and human-understandable location descriptions.

2.3. **Service Exposure**

The telecommunications industry is one of the most profitable businesses in the world today. Network vendors, device manufacturers and mobile operators have made enormous profits [30]. According to the International Telecommunication Union (ITU), as of 2013, there are 6.8 billion mobile-cellular subscriptions nearly approaching the world's population of 7.1 billion. Despite fierce competition among operators, the industry remains financially stable. Demand has been sufficient to ensure profits for operators [31].

However, recent trends show that there are external threats that could pose serious dangers to their market. One major signal is the decline of mobile device manufacturers like Nokia and Motorola and the dominance of internet giants like Google and Apple. This has been attributed to the fact that these device manufacturers underestimated the power of the ecosystem [5]. The same goes with operators as well. In many markets, average revenue per user (ARPU) as well as average profit per user (APU) has been decreasing [5]. New network technologies such as High Speed Packet Access (HSPA) and Long-Term Evolution (LTE), that bring high-speed data connectivity to users has in fact brought about new profit challenges to operators from OTT (Over The Top) players.

Internet alternatives are posing major challenges to mainstream mobile services such as voice and messaging. OTT competitors such as Facebook, GoogleTalk and Yahoo are predicted to cause major drops in voice and messaging revenues. On the other hand, operators' own alternative to OTT, Rich Communications Services (RCS) has received very little traction [5].

Open Innovation through open APIs is credited to be the cornerstone of the success of Internet companies. The ecosystems approach that Apple and Google took by exposing device capabilities to developers is a classic example of Open innovation via Open APIs [5] [32].

Mobile networks have hitherto followed the walled-garden approach of closed innovation. The main idea being that core services are standardized and offered only by operators. The underlying technologies are complex and not designed for external developers. Hence, there is severely limited scope for open innovation and implementation of novel ideas.

With the advent of computationally powerful smartphones and high speed internet access through 3G, HSPA and LTE, internet companies continuing to follow the open innovation model through open APIs, are able to bypass operator control and invent and develop disruptive innovations.

2.3.1. **The Open Telco concept**

In the Open Telco concept, operators open network resources to developers, partners and themselves in a usable form. There are already some initiatives in this direction such as Mobile Web 2.0, Telco 2.0, Network as a Service (NaaS) and OneAPI.

The key idea is to provide mobile network resources through well defined, simple and secure APIs that are made available to interested parties. External developers and partner companies can then use these APIs to build novel services. Secondly, operators can themselves utilize the same APIs for analyzing customer data [5].

2.3.2. **Challenges**

The basic idea of the Open Telco is simple, but unfortunately the practical implementation involves several challenges in regards to technology, business, security and regulation issues. The Operators circle has always been characterized by extreme competition and price wars. Cooperation among operators has been minimal and the market is highly dispersed. For Open Telco to succeed, a very high level of cooperation will be required across operator boundaries [5]. Operator deployments often include several technologies (GSM interworking with WCDMA and LTE) bundled together and major changes are complex and expensive. These technologies were not designed with service exposure in mind. Hence, exposing the data is not an easy task.

CHAPTER 3

DEMO SYSTEM AND SERVICES

In this chapter, details of the indoor positioning system developed as part of this Thesis are presented. The technologies used, the applications developed and the algorithms utilized are discussed.

This chapter also delves deeper into the idea of location-based services in terms of their scope and applications. It ends with a proposal for a platform that could be used to build location-based services.

3.1. Detailed description of EricsPoint

An indoor positioning system named 'EricsPoint' was developed in the course of this Thesis. EricsPoint was created as part of a study on indoor positioning systems carried out in Ericsson, Finland in collaboration with Aalto University. The system was developed jointly with the help of Ville Miekk-oja and Teemu Aura.

3.1.1. System Overview

The Indoor positioning application developed as part of this Thesis is based on WiFi fingerprinting. The system consists of two applications running on mobile devices, one for fingerprinting and another for the actual positioning. In practice, the devices only send RSS data to and receive the position estimates from the server. The positioning algorithms and computations are run on the server.

The server running at the back-end stores the fingerprints and calculates the position estimates. This reduces the computational load on the mobile devices and makes the entire system robust. Complex algorithms can be put into use without concerns about systemic lags or delays. It also brings in flexibility, as the positioning-related algorithms running on the server can be modified independent of the applications running on the mobile devices.

The algorithms that have been used are:

- Probabilistic relation based algorithm

- Anchor System
- Transition System

These will be described in further detail later in this chapter.

The mobile devices and server communicate via internal WiFi. To demonstrate the indoor positioning system a webpage that displays the current position of all users of the system, was developed. Figure 3.1 shows a representation of the flow of information that occurs during both fingerprinting and positioning.

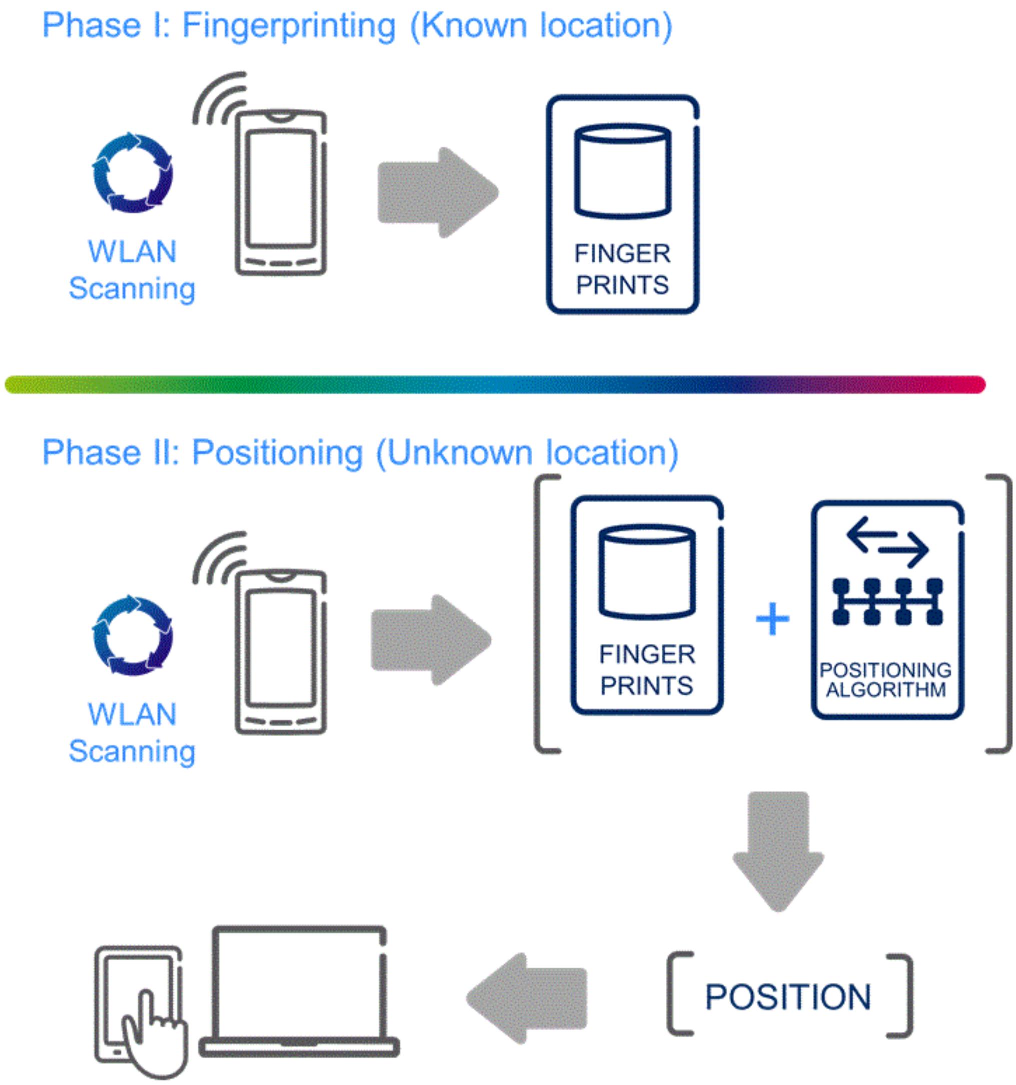


Figure 3.1: WiFi fingerprinting phases

3.1.2. **Test Area**

The area chosen to test the indoor positioning system was the central seating area called 'Länsitori' in Ericsson's Jorvas office in Finland (see Figure 3.2). A WiFi test scan performed using WiFi analyzer [33] revealed over 30 WiFi APs, thus making it a suitable test area.

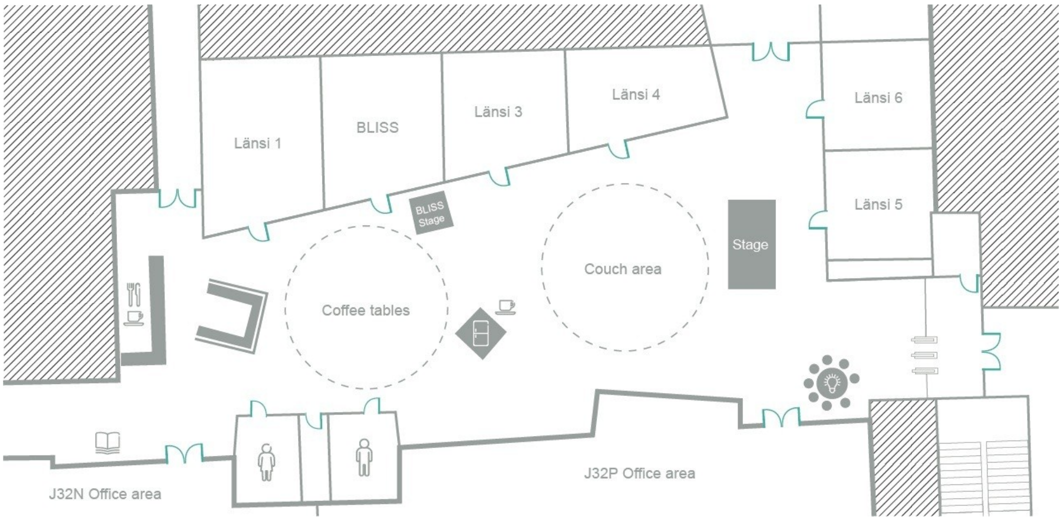


Figure 3.2: Map of test area

Länsitori also has different functional areas such as a library, a cafe, a stage and several surrounding meeting rooms. It is also frequented by employees throughout the working day. Thus it is a good space to test the effectiveness and robustness of the system and also carry out user tests.

Ericsson's Jorvas campus also has an internal WLAN. This can be used to access the positioning server over WiFi, as opposed to using a 3G data connection. Thus, once the mobile device is connected to the internal WLAN, it has low latency and quick access to and from the server.

3.1.3. **Why Android smartphones were used?**

The mobile device used for the positioning application should have a WiFi antenna. There should also necessarily be some means to control the WiFi scanner and obtain the resultant RSS data. It would also be useful to have a touchscreen, so that the user could be visually shown his current position on the map. The screen would be even more valuable during fingerprinting phase where the user needs to communicate his position once at a reference point. Since fingerprinting is a tedious process, it would provide additional value to design the related application so that fingerprinting is simple and quickly done.

With all this in mind, a smartphone or tablet with an operating system that provides a software development kit (SDK) to support third party application development would be the best choice for building the fingerprinting and positioning applications.

Since Apple's iOS's SDK does not give access to the device's WiFi antenna, an iPhone could not be used to develop the applications. On the other hand, the Android SDK provides methods that enable interaction with the device's Wi-Fi hardware through simple built-in APIs. Thus, the choice was made to use Android devices. Microsoft's Windows phone was a candidate as well, but given Android's maturity and extensive online support, the choice towards Android was made.

3.1.4. **Overall principle**

The underlying assumption of fingerprinting is that a certain characteristic of a physical point in space remains stable in time and unique in space. In an indoor environment with multiple stationary WiFi APs pre-installed for internet connectivity, WiFi RSS is an obvious choice as the characteristic. WiFi routers are positioned so that their signals reach every part of the building to ensure wireless connectivity everywhere. This works in favour of WiFi fingerprinting. Secondly, though the signal propagation is unpredictable for constructing a simple signal propagation model, it is stable enough to be used for fingerprinting if sufficient number of APs are used [34].

The fingerprinting technique is divided into two phases- fingerprinting and positioning. In the fingerprinting phase, RSS values from available WiFi APs are measured throughout the test area at positions called RPs or reference points. Thus a radio map is created.

During the positioning phase, the RSS readings at an unknown position are taken and sent to the server, where they are compared with existing fingerprints. Here, algorithms estimate which stored position's fingerprint is closest to these RSS readings. The resulting position is estimated to be the unknown position.

Fingerprinting phase

An RSS fingerprint is defined as the set of WiFi APs' media access control (MAC) addresses with their respective signal strength values, all received at a particular point in the indoor area.

In the database, a fingerprint is denoted as a set $\{(P_i, F_i \mid i= 1,...N)\}$ where P_i denotes the coordinates of RP i and $F_i = [\ f_{i1}, f_{i2}, \ldots f_{iL}\ ]'$ refers to the RSS readings vector for RP i, with f_{ij} referring to the RSS reading from AP j received at RP i. N is the total number of RPs and L is the total number of APs.

An example fingerprint is shown in Figure 3.3. Here the location_number is a name used to easily identify each fingerprint. This name is given by the fingerprinter. Pixels refers to the X, Y coordinates of RPs on the map image. These coordinates have a one-to-one mapping to the physical location where the fingerprint was taken. The ap_mac column stores the MAC address of each detected AP.

A single WiFi scan is unreliable for getting RSS estimates. Hence several scans are made at each RP and the average and variance from each AP are calculated. These values are stored in the 'average' and 'variance' columns. 'Values_num' is the number of times the AP was actualy detected during the scans.

Thus, the fingerprint database contains a mapping between a physical location's identifier (coordinates as pixel values and 'location_number') and the set of all APs' MAC addresses detected at that location and their respective RSS measurements. Information about this mapping is stored in a database called 'Fingerprint database' for use in the positioning phase.

The choice of the physical location depends on the application, the accuracy required, the expected error and even the type of indoor map available. It could vary from an entire room, corners of each room, an area with a function to an actual physical location where a person stands.

location_number ▲	ap_mac	average	variance	values_num
east wing_1	00:0f:61:10:1f:b1	-57.5	5.85	10
east wing_1	64:31:50:e6:21:51	-74.6	6.24	10
east wing_1	00:0d:67:28:46:89	-66.7	2.41	10
east wing_1	00:0d:67:28:46:88	-65.9	2.49	10
east wing_1	00:0f:61:10:62:51	-78	13.6	10
east wing_1	00:0d:67:4d:d6:3c	-88.6	13.24	10
east wing_1	64:31:50:e8:a3:11	-74	0	10
east wing_1	64:31:50:e7:8c:72	-71.9	4.29	10
east wing_1	00:0d:67:28:46:87	-66.2	1.76	10
east wing_1	00:0d:67:4d:d6:3b	-92.6	2.24	10

location_number	pixels
east wing_1	361,177

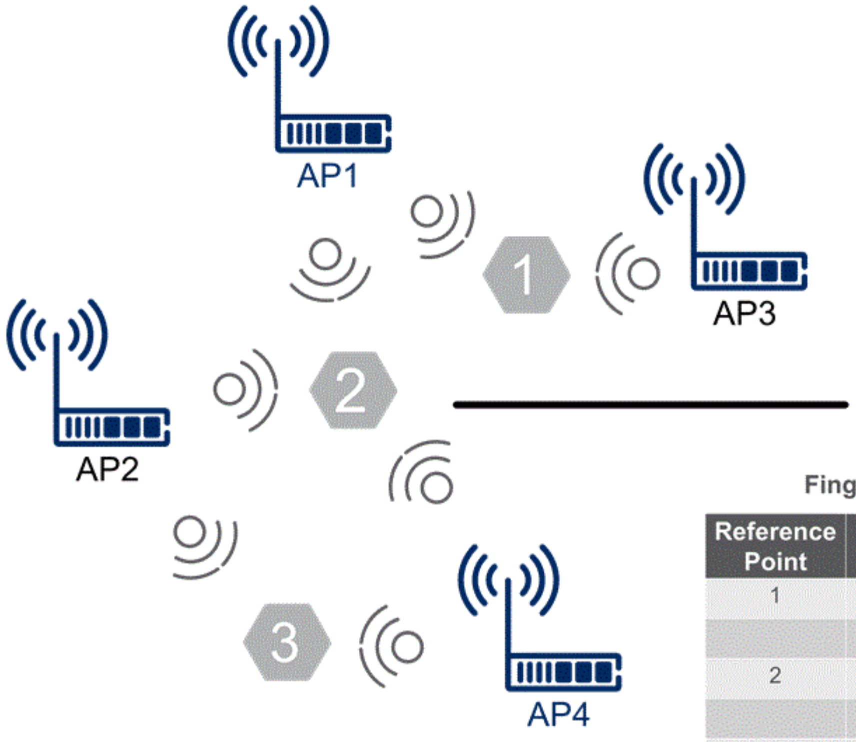
Figure 3.3: An example fingerprint in database

A location identifier is any value that is unique to the location. This value could be any or all of the room name (for example, Living room), an area within the room (for example, Living Room-North), the function of the area (for example, coffee area or bookshelf), the actual physical coordinates (100, 200) or even a random number depending on the application. In 'Ericspoint', the 'location_number' and 'pixels' together form the location identifier.

Access points or APs refer to WiFi transmitters or beacons installed within the indoor environment. Every AP must be stationary during both fingerprinting and positioning phases. They can be secure or unsecure, private or public. Also, it is not necessary to know exactly where each AP is located beforehand. An AP is said to be visible if it can be reliably and consistently found on performing a WiFi scan. Each AP is identified uniquely by its own MAC address [20].

Every transmitter transmits signals at a certain power level. But the RSS, which is basically a measure of the power level detected by a scanner, varies from place to place depending on factors such as the distance to the AP, the presence of barriers such as walls and other fixtures between, people moving about etc. It is also affected by physical effects such as multipath and diffraction. Finally, the detected value also depends on the device used for scanning and its antenna sensitivity. RSS is measured in dBm.

The points or positions where fingerprinting is carried out are referred to as RPs (see Figure 3.4). The amount and distance between the reference points can be varied. In general, the more there are reference points, and the denser they are, the better the positioning result.



Fingerprint Database

Reference Point	Access Point	RSS
1	AP1	RSS1
	AP3	RSS2
2	AP1	RSS3
	AP2	RSS4
	AP4	RSS5
3	AP2	RSS6
	AP4	RSS7

Figure 3.4: Fingerprinting in practice

Positioning Phase

During this phase, pattern recognition algorithms are employed to obtain the best estimate of the user's indoor location.

The assumptions behind this phase are:

- Fingerprinting has already been carried out in the indoor area, before positioning is attempted.
- Positioning is carried out only while the user moves within the confines of the fingerprinted area.

Positioning involves reverse-mapping the user's current unknown location from the information obtained by performing a scan of WiFi APs at that unknown location. The scan reveals the APs visible at that position (identified by MAC address) and their respective RSS values. This set of values is compared with the known RSS values of each location in the fingerprint database, to obtain the similarity between the unknown location and every known location. The location that is closest or least distant from the unknown location gives the user's location.

A number of mathematical tools and algorithms are employed to make the above-mentioned comparison. Details will be discussed later in this chapter.

3.1.5. **Positioning algorithms**

The principle idea of the position estimation algorithms is RSS values pattern-matching i.e finding the likelihood that two signal strength measurements are taken at the same place [35].

This pattern-matching involves mathematical algorithms and can be broadly classified into two categories, the deterministic approach and the probabilistic approach [20].

In the deterministic method, the measured RSS values from each WiFi AP are averaged over several scans. Then, for each position in the database the distance between user signal strengths and database signal strengths are calculated. The position with the smallest distance is selected as the best estimate of the target's location.

In the probabilistic method, the objective is to find the most probable position. The RSS distribution is modeled and a numerical probability is assigned to each fingerprint expressing how close it to the unknown RSS readings. This gives an idea of distance between signal strength vectors.

In the probabilistic method, the objective is to find the posterior distribution of the location, which is the conditional probability $p(p_i \mid r)$ [20]. This is estimated by using the Maximum A Posteriori (MAP) estimator, which is derived from Bayes' rule.

$$\hat{p}_{MAP} = \arg_{p_i} \max f(p_i \mid r) = \arg_{p_i} \max \frac{f(r \mid p_i) f(p_i)}{\sum_{i=1}^{N} f(r \mid p_i) f(p_i)} \tag{3.1}$$

where $f(p_i \mid r)$ and $f(r \mid p_i)$ are the conditional probability density functions.

Since the denominator remains the same regardless of the choice of p_i, it can be ignored. The prior density function $f(p_i)$ is assumed to be uniform, as there is no prior knowledge of the device's location. As a result MAP estimation transforms into a Maximum Likelihood (ML) estimation.

$$\hat{p}_{ML} = \arg_{p_i} \max f(r \mid p_i) \tag{3.2}$$

Literature shows that the probabilistic approach is a much more robust way of performing this pattern matching as compared to the deterministic approach [15].

In this Thesis, the position estimate is calculated during the positioning phase using an algorithm termed as 'Probabilistic relation-based positioning'. This estimate is further improved with secondary techniques called the 'Anchor System' and 'Transition System'.

Algorithmic principles and assumptions

Given the variation and unpredictability of WiFi RSS values detected at a point over time, a single scan of WiFi APs at the reference points is not sufficient to be a good fingerprint. Hence multiple scans are carried out at each RP during the fingerprinting phase.

While designing the probability-based algorithm, it is necessary to model the signal strength distribution. Literature and researchers are divided on whether WiFi signal strength distribution is Gaussian or not in dB scale. Several authors propose non-Gaussian likelihood functions in their algorithms. However most approaches assume Gaussian signal strength distribution, justifiable by maximum entropy arguments or the law of large numbers acting on multiple additive error sources [35]. Hence this approach is followed in this Thesis.

Every WiFi antenna differs in its size and sensitivity. Thus the RSS values vary from device to device at the same location at the same time. As a result, positioning does not work very well when carried out on a different device as the one used for fingerprinting. Hence normally, the same device needs to be used for both positioning and fingerprinting.

However it has been observed that while using different mobile devices, the ratio of absolute RSS values (or difference in dB scale) detected from APs remain quite stable. Between various mobile devices, the difference in RSS-values in dB scale detected at a point from various WiFi APs is found to be a more robust measure to be used in positioning algorithms than absolute RSS values [36]. Hence, a positioning algorithm that utilizes the ratio of RSS values instead of their absolute values could be used on different devices.

Since radio signals attenuate logarithmically with increasing distance [2], RSS values are substantially higher near an AP than anywhere else. Thus, APs can be set as anchors. If a particular AP's RSS value is detected to be sufficiently high, it is very likely that the device is located near that AP. This algorithm however requires precise knowledge of the location of APs.

Temporal information can also be used to affect location probability. Positioning can be improved by taking into account past positions. Once a user is known to be at a particular position A, it follows that the next position cannot be very far from A. Thus, likeliness of positions near A can be increased.

Actual Algorithms used in EricsPoint

The indoor positioning system developed in this Thesis utilizes three independent algorithms

- Probabilistic relation-based algorithm
- Anchor System
- Transition System

Probabilistic Relation-based algorithm

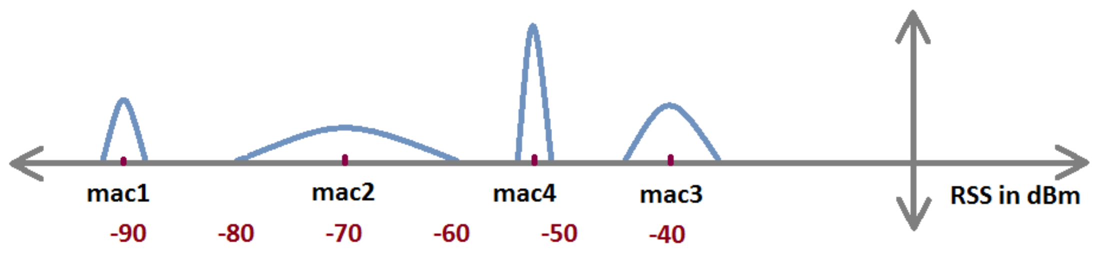


Figure 3.5: Fingerprint of a reference point A

Assuming that RSS values are Gaussian distributed, the RSS values of a particular AP in a fingerprint are defined by two parameters namely average and variance. Thus the fingerprint for a particular location consists of mean and average RSS values for each AP visible at that point, as illustrated in Figure 3.5.

During the positioning phase, instead of comparing the unknown position's RSS values directly to the fingerprint database, the algorithm compares relations or differences in RSS (measured in dB scale) between APs taken in pairs. This makes it possible to use a different physical device during positioning than the one used for fingerprinting [35].

It is known that the difference between two Gaussian distributed random variables is also a Gaussian distributed random variable, whose mean and variance can be directly computed from the mean and variance of the component random variables.

Given two random variables X and Y that are Gaussian distributed with means μ_x and μ_y and variances σ_x and σ_y respectively, the relation or difference between them is also a Gaussian distributed random variable Z. Mean, μ_z and variance σ_z of the random variable Z, are then given by

$$\mu_z = \mu_x - \mu_y \tag{3.3}$$

$$\sigma_z = \sqrt{\sigma_x^2 + \sigma_y^2} \tag{3.4}$$

Overall, the algorithm works as follows. Once the fingerprinting phase is complete, the database is updated with fingerprints and the locations where they were taken. During positioning, WiFi RSS readings are taken at the unknown location. For each location in the fingerprint database, the Gaussian probability density function is derived and computed for each common relation between the APs visible at the unknown location and the location fingerprint. A common relation is one that contains the same pair of APs.

The probability density function thus becomes

$$f(z)=\frac{e^{\left(-\frac{(z-(\mu_x-\mu_y))^2}{2(\sigma_x^2+\sigma_y^2)}\right)}}{\sqrt{2\pi(\sigma_x^2+\sigma_y^2)}} \tag{3.5}$$

The results are summed and normalized by dividing by the number of relations to give the probability of that location being the unknown location. Normalization is needed because the number of common relations can vary greatly between locations.

$$P(L)=\frac{\sum_{i=1}^{n} f(z_i)}{n} \tag{3.6}$$

Finally the fingerprinted location with the highest probability value is estimated as the unknown location.

To better understand the idea of common relations, suppose the fingerprints at two RPs, 'P' and 'Q' are such that at both RPs, 4 APs are visible. The respective RSS values in dB scale are stored as shown in Table 3.1.

Fingerprint of RP 'P'	Fingerprint of RP 'Q'
[MAC_A: RSS1]	[MAC_B: RSS5]
[MAC_B: RSS2]	[MAC_C: RSS6]
[MAC_C: RSS3]	[MAC_D: RSS7]
[MAC_D: RSS4]	[MAC_E: RSS8]

Table 3.1: Fingerprints of RPs 'P' and 'Q'

During the positioning phase, at an unknown location, say X, 4 APs are visible and the respective RSS values are shown in Table 3.2.

[MAC_A: RSS9]
[MAC_B: RSS10]
[MAC_D: RSS11]
[MAC_E: RSS12]

Table 3.2: List of RSS values at unknown location

Hence the common relations are (shown in Table 3.3):

Between RP 'P' and 'X'	Between RP 'Q' and 'X'
RSS(MAC_A) - RSS(MAC_B)	RSS(MAC_B) - RSS(MAC_D)
RSS(MAC_A) - RSS(MAC_D)	RSS(MAC_D) - RSS(MAC_E)
RSS(MAC_B) - RSS(MAC_D)	RSS(MAC_B) - RSS(MAC_E)

Table 3.3: Common relations

Here, MAC_A refers to MAC address of AP A. RSSx refers to a distinct RSS value received from a particular AP. RSS(MAC_X) refers to the detected RSS value of AP with MAC address MAC_X.

Anchor System

Some RPs and their related fingerprints have high RSS values from certain APs because of physical proximity to the AP. Thus if the RSS reading from one of these APs is higher than a pre-defined threshold value, the probability of being near that AP is extremely high.

The idea behind the 'Anchor System' is to boost the probability of positions near the Anchor AP if its signal strength is found to be higher than a defined limit value. The limit value is defined by the person performing the fingerprinting.

Transition System

The 'Transition System' takes into account past location estimates to influence probability of future location estimates. Past position estimates are stored into a 'history_positions' table that are then used in the 'Transition System'. The system estimates the maximum distance that the user could have walked from the past position and increases the probability of positions that fall within that radial distance.

Distance is calculated from the time difference between the current and past positions, and the maximum average walking speed of a user which is predefined to 7 kilometres per hour (the average is around 5 kmph) [37].

$$D = t_{diff} * v \tag{3.7}$$

where 't_{diff}' is the time difference and 'v' is the walking speed

The distance between positions is calculated from the pixel values of the positions and the metre/pixel ratio. This ratio is obtained by physically measuring the test area and is set beforehand.

Software Implementation

The algorithms and descriptions from above have been implemented in software. The calibration and positioning applications are written in Java and implemented as Android smartphone applications.

At the back-end is a (Linux Apache MySQL PHP) LAMP server called 'Inno' [38]. MySQL is the database system used. The server side algorithms are written in PHP. Inno is a desktop PC running a linux-based operating system. Below is a brief description of the software components

Fingerprinting

During fingerprinting, the client side application EricsCalibration is used to construct the radio map of the test area. Once the fingerprinter positions himself at a particular RP with the device, EricsCalibration scans for WiFi APs, a user defined number of times and records the detected APs' MAC addresses and RSSs values. It also associates this data with the RP's location information, namely 'location_number' and coordinates on the map.

Adjusting the number of scans and one scan's duration affects reliability, the longer and more the scans, the more accurate the fingerprint database is. For this Thesis, each scan consisted of 10 scans of 1 second duration each.

After the scanning activity, the results are gathered together in an XML string along with information about location and orientation (similar to the one shown below). This string is sent to the Inno server.


```
<?xml version='1.0'?>
<session>
<number>4</number>
<coordinates>100,200</coordinates>
<location_number>COFFEE_AREA</location_number>
<content>
<item>
                <MAC>00:19:77:68:34:d6</MAC>
                <SIG>-46 -48 -47 -46 -46 -46 -44 -46 -45 -45</SIG>
        </item>
<item>
                <MAC>00:0d:67:28:36:a3</MAC>
                <SIG>-63 -59 -58 -59 -59 -59 -59 -59 -59 -59</SIG>
        </item>
<item>
                <MAC>64:31:50:e6:21:91</MAC>
                <SIG>-62 -61 -62 -59 -62 -62 -53 -53 -55 -54</SIG>
        </item>
<item>
                <MAC>0a:60:6e:bc:d2:b1</MAC>
                <SIG>-68 -69 -71 -70 -67 -66 -65 -67 -66 -67</SIG>
        </item>
</content>
</session>
```


During fingerprinting, the Inno server receives the XML-formatted data from the EricsCalibration application, calculates the mean and average of RSS values and populates the fingerprint database with it.

Design

As fingerprinting is a cumbersome and laborious process, an attempt was made to improve the design and user-experience of the tool.

The location_number number is a text/numerical value that the fingerprinter can define. The map interface is such that there is a stationary cross-hair at the center of the screen. The calibrator can pan the map up, down, left or right and pinch zoom like any touchscreen image. As the map moves across the screen relative to the cross hair, the x and y coordinates are updated so as to always reflect the position of the cross hair on the map, as illustrated in Figure 3.6. The result is that the calibration process is much faster.

When there is a need to fingerprint a RP again or if the ‘location_number’ text was set incorrectly, the database needs to be updated or corrected. Instead of manually deleting the database entries, a new fingerprint taken with the same coordinates will update the database. This was done to improve the usability of the application.

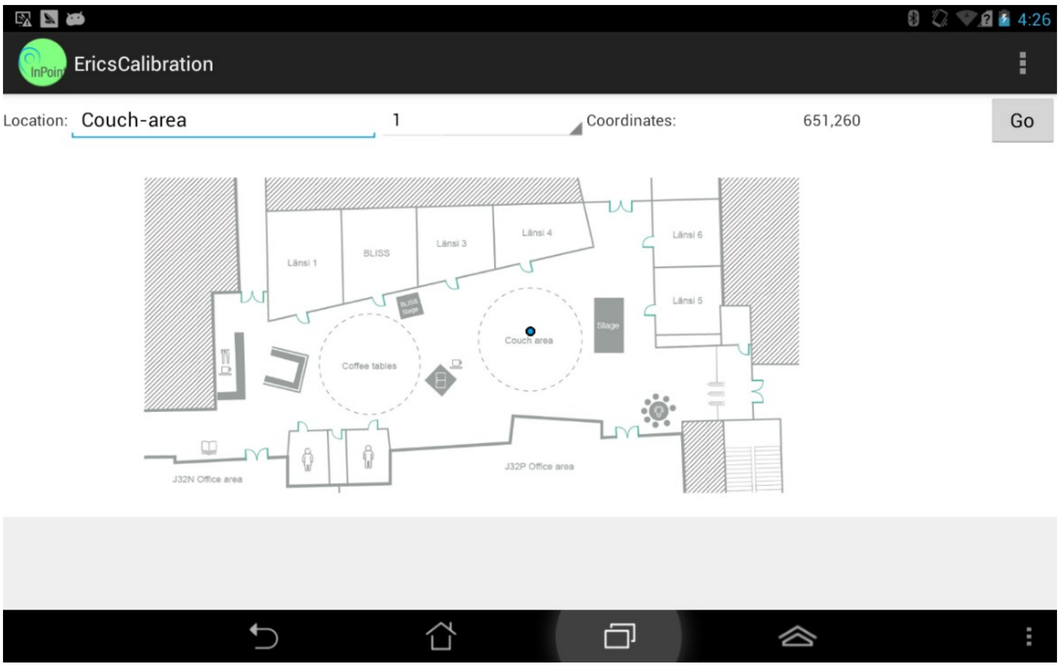


Figure 3.6: EricsCalibration screenshot

Positioning

The positioning application, called EricsPoint, displays the user’s location on the indoor map. This is the same map as the one used during fingerprinting (Figure 3.7).

For the purpose of identification, the user is required to enter his/her name in a text box. As the positioning application is meant to track the user, the application automatically and periodically (every 5 seconds) scans for WiFi APs and sends the resultant RSS readings to the server as an XML.

Using these RSS readings and the fingerprint database as input to its positioning algorithms, the server estimates the user's position and returns this result to the application. The positions database is also updated with the user's name and position estimate.

The EricsPoint application extracts the coordinates of the position estimate from this result and updates the map that the user sees. The location_number text value i.e the name that the fingerprinter had given to the RP, is also displayed separately in a text box. This is so that in addition to observing one's location on the map, the user is also told of his/her location in a textual format.

The system can handle several users simultaneously. Once fingerprinting was done using a tablet, the EricsPoint positioning application was installed and run on four other devices simultaneously. The system functioned without any major issues. Thus, in effect the positions database contains the real-time updates of each user's location.

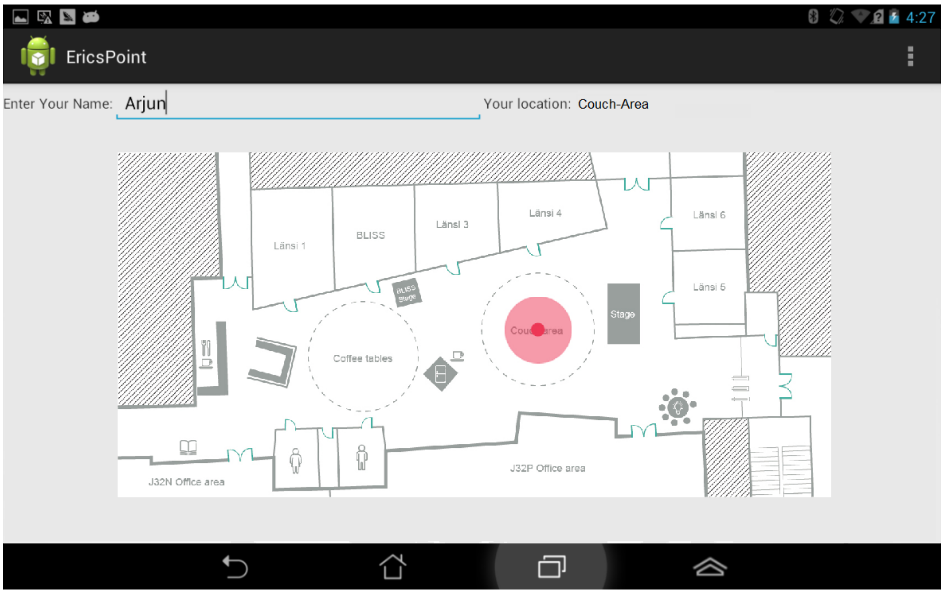


Figure 3.7: EricsPoint screenshot

Webpage

To demonstrate the indoor positioning system a webpage was developed as well (Figure 3.8). This webpage is hosted on the Inno machine. The webpage takes as inputs the graphical map and the positions database and displays the current location of all user's currently running the application along with their usernames.

Figure 3.8: Webpage screenshot

3.2. Location-Based Services

As explained, LBS or location-based services take into account the location of the mobile device. A literature study of LBS was carried out and the results are presented here.

3.2.1. Types of location information

As the first step in analyzing Location Based Services, it is important to understand how location can be described and what kinds of location information can be used to build services.

According to [39] a device's location can be described in three ways - geospatial coordinates, civil addresses and location attributes.

Geospatial coordinates refer to the latitude, longitude and altitude of the device. They can be acquired using GPS receivers. They are usually used outdoors where GPS signals can be easily acquired. These coordinates uniquely identify a location and can be used to display location on a map.

Civil addresses are similar to postal addresses. A civil address may refer to a single building for outdoor locations or a specific room when referring to building-level indoor locations. There exist some standards for civil addresses. Postal codes are used worldwide, but quite often location names are not unique. Hence, human intervention and local knowledge is often needed to decipher and map addresses to locations. However, compared to geospatial coordinates civil addresses are easier to understand for end users.

Location attributes describe aspects or properties of a certain location that can influence communication behavior. These can be applied to both indoor and outdoor locations. This requires not just knowledge of the location but also a reasonable amount of familiarity with the activities carried out there.

Another approach [40] is to revisit the idea of a map and see it as not just a physical, visual map but a framework to represent and communicate location information. Physical maps are static but location information is often dynamic and dependent on the service offering. Seen from the perspective of building Location Based Services, location content can be described in many ways which can be placed into several layers that model the real world.

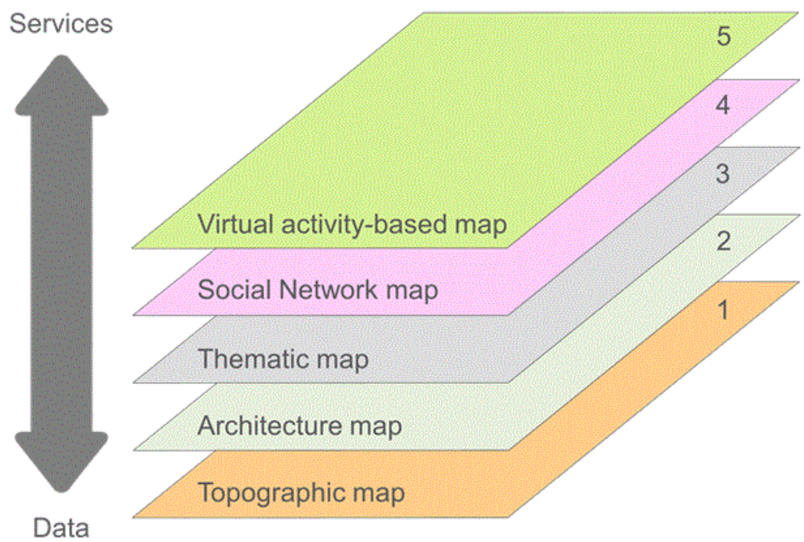


Figure 3.9: LBS classification model

A layered LBS classification model in proposed in [40] wherein location information is divided into five layers as shown in Figure 3.9. Higher layer maps tend to be more dynamic and also more suited to building services.

1. The topographic map depicts purely geographic information, such as rivers or hills.
2. The architecture map depicts physical facilities built by humans, such as cities and buildings.
3. The activity/theme layer describes the activities planned or occurring in the area, such as a restaurant or a theme park.
4. The social network maps the location and activities of other users in relation to the user in question and organizes it meaningfully, such as finding friends or avoiding bosses.
5. Finally the virtual-activity based map focusses on virtual activities with other participants, in a way combining the previous two layers. Examples could be geo-fencing and location-based games.

In the prototype location-based service developed as part of this Thesis, location information from layer 3 is utilized.

Conventionally maps are represented visually. This is because a scaled representation of the physical environment is the most straightforward means to communicate geographical data and hence position information. However, navigating using a visual map is not a trivial task for most users especially when the area is unfamiliar. In such situations an audio map or providing visual cues instead of a hand-held map could be more useful.

3.2.2. **Types of Location-Based Services**

Location-Based services can be classified into location-tracking services and location-aware services [22]. While location-aware services provide the user with personal location data and related services, location-tracking services supply a user's location information to external entities.

It is important to distinguish between location-tracking and location-aware services but from end-user experience perspective as well. Location tracking services focus only on the user's location coordinates while location-aware services take into account user's context as well as the context of the surroundings. This enables these services to provide a socio-technical fit and gives them a much wider scope for differentiation and creativity.

Trends show that location-based services are becoming less and less about the visual aspect and more dependent on other data factors. A simple example is a car navigation system that redirects based on real time traffic information. Another trend is aggregating location data from larger groups without identifying individual users. This could be to gauge usage patterns statistically to optimize the telecom network or to quickly react to dynamic user movement, for example to redirect bus routes in case of a concert or riots. An interesting aspect of such applications is that they have no privacy risks [41].

A user's workplace and home location can be inferred from information about where and at what time of day he spends his time usually.

3.2.3. **Challenges**

Building location-based services is more challenging indoors than outdoors. A lot of information and content about outdoor locations is publicly available on the internet from sources such as Google, OpenStreetMap and yellow pages. Additionally as a technology, GPS works very well outdoors all over the world and thus can be used as a standard way to obtain and exploit outdoor location information. Thus technologically and from the perspective of information access, outdoor location-based services are relatively easy to develop.

On the other hand, building indoor location-based services is fraught with challenges. Today's indoor positioning systems are based on several technologies [2]. Also, in the absence of standardized interfaces the techniques used and products developed do not work together. Standardization efforts have been fragmented and disjoint [42]. Furthermore, the data required to build indoor location-based services is often temporal and contextual, and hence its collection cannot be automated easily. Lastly, indoor maps are difficult to obtain as they are not publicly available.

3.2.4. **Location and granularity**

Location information is inherently hierarchical. For example a postal address is usually described in the following order:

1) House Number
2) Street name
3) City
4) Postal code
5) Country

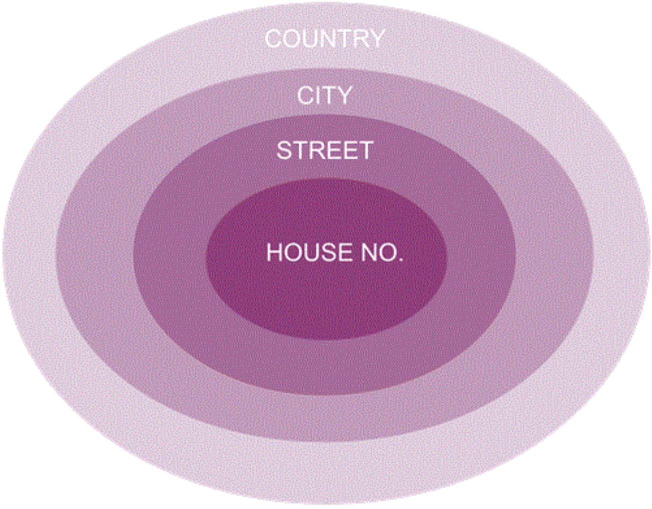


Figure 3.10: Granularity of an address

Thus parts of an address can be visualized as many concentric circles, as shown in Figure 3.10. Most studies on location granularity focus on its utility as a means to ensure user privacy [43]. However, the idea of granularity can also be used to classify location-based services. Not every service requires street level accuracy. For example, a weather service only needs to know the user's zip code or city. Thus, location-based services can be categorized based on the minimum necessary level of granularity.

Firstly, this would ease information gathering, since obtaining country-level information is easier than city-level information especially in the telecom network. Additionally, user privacy is ensured. A user could permit a service to access his location only until its minimum required level of granularity, thus ensuring that sensitive data is not distributed.

3.3. **Service Exposure**

Service exposure is a phrase that has become very popular in the internet world. This is attributed to the success of the ecosystem approach in the mobile phone (Apple, Android) and web services (Google, Amazon, Facebook) industries [5] [32].

However its usage in the telecommunications industry is a fairly recent phenomenon. Service exposure in the telecom context is about operators providing external developers access to their network assets, thus enabling them to build their own unique services and applications [44].

It is important to note that exposing network assets through APIs is not a new concept for operators. There have been APIs catered towards individual capabilities such as messaging, payment and location-based services. However, these have received a lukewarm response [45].

The learning from this failure is that service exposure cannot be built upon the opening up of single individual APIs. The need is of a service exposure platform complete with documentation, SDKs and test environments [8] [44]. The interfaces to network assets should be such that each node can be seen as a black box with its internal structure hidden, exposing only the required functionality. Moreover, there should be a clear separation between the exposed network assets and service exposure. Lastly, developers and content providers should be seen not as paying customers but as partners with a share of the revenue [32] [45]. Successful examples of these platforms are the Apple's iOS and Google's Android.

Open Telco is an initiative that opens up operators' network resources to developers, partners and even themselves through well-defined, simple and secure APIs made available to all interested parties. Thus freed from the complexities of the internal workings of the mobile network elements, developers can create 'mashup' services. These are services that bring together and leverage functionality and data from several different sources. In this context these sources are mobile network assets and information from the internet and other services. Mashup services have proved to be very successful in the internet and smartphone applications market. [6] [45]

Thus, operator networks that have hitherto been hidden would follow the Network as a Service (NaaS) service model in accordance with the cloud computing service model [5].

3.3.1. **Business case**

From the business perspective, operators see service exposure as a means to move up the value chain and compete with Over The Top (OTT) players, instead of just providing internet connectivity. They see in it the potential to create a new set of business opportunities in partnership with developers and content providers [45].

In the current scenario, OTT players are competing strongly with telcos for revenues. Without any strong means to differentiate themselves, telcos compete with one another essentially on price and quality. As a result prices have come down drastically and network quality has improved. Consequently, OTT players are able to provide a wide range of competing services over the operators' network. This is made worse by the fact that consumers today take good voice quality, high speed data connectivity and universal coverage for granted [32].

The business case of the Open Telco model is a hybrid one, lying between the Internet's open-system model and operators' traditional walled-garden approach. Operators control and provide connectivity and billing, while giving up control over the actual services provided [6] [46]. Hence, there is a balance between openness and control.

Parallelly, unnecessary complexity is avoided. Fair revenue sharing ensures growth of the developer community while ease in service provisioning for consumers enables business volume growth [46].

It is valuable to bring location-based services into this discussion. Current location-based services (based on GPS or cell ID) are gaining in popularity and users' location information is being seen as an enabler rather than an independent service. This trend combined with the business case for operators to make their assets more open makes the study of LBS in the context of Open Telco APIs interesting [6].

3.3.2. **Architecture**

The key principle behind the service exposure architecture is that each node or subsystem that delivers a certain capability operates as a black box to the API user. The internal structure and functions are hidden and protected [44] [45].

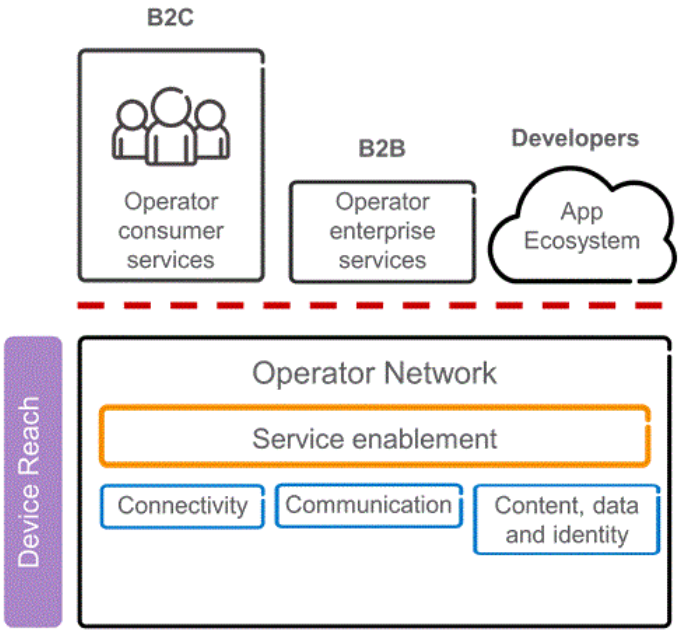


Figure 3.11: Simple Service Exposure Architecture

Another necessary feature is a clear line that separates service exposure (act of providing a service) and the exposable services (network elements' capabilities) as shown in Figure 3.11.

3.3.3. **Assets to expose**

There are several assets owned by telecom operators that can be exposed in the form of network APIs. Some of the broad categories are:

- **SMS, MMS**: APIs allowing developers to send, receive and obtain message delivery status.
- **Location**: APIs designed to pinpoint user location.
- **Payments**: APIs that link payments so that external purchases can be paid via the phone bill.

- **Voice/Speech**: APIs that allow developers to bring in voice and transcription services into their applications, thus making it easier for users to interact with the service.
- **SDM/Identity Management**: SDM stands for Subscriber Data Management. SDM exposure would bring together unified customer information into a central database.

Chapter 4

SERVICE PROTOTYPES

This chapter describes the development and demonstration of two example location-based service prototypes, 'Friend Finder' and 'Exhibition Navigator' built as part of this Thesis. Technically, they required the integration of the Indoor Positioning System, EricsPoint and the Service Exposure platform, Ameche. The prototypes also depend heavily on the learnings gained from the study of location-based services.

4.1. Development phases of EricsPoint

Once the positioning algorithms were in place, EricsPoint functioned in the test area with sufficient accuracy. However, to adapt the system for the deployment of a location-based service, several modifications were necessary. Below are described the different stages of the system's evolution.

It is worth recalling here that to simplify the user experience of the positioning application, it was designed to function without any user interaction, besides entering his/her name. Thus the user walks about the test area with the application running and is shown his/her position in real time (position is updated every 5 seconds).

4.1.1. Phase A

In phase A, a grid was drawn over the map with lines 2 metres apart within the indoor area. Each intersection point was treated as a RP. Also, each point was fingerprinted with three orientations. Thus the expected accuracy was 2 metres.

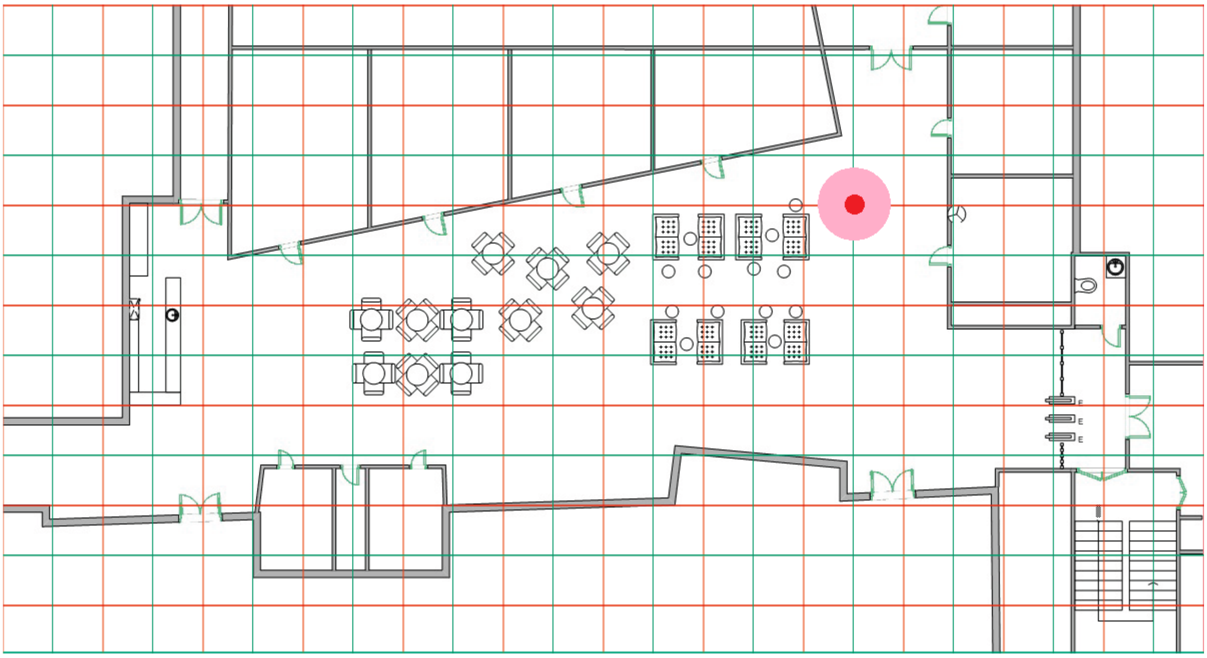


Figure 4.1: Initial map

Each fingerprint was given a unique identifier called 'location_number', which was set by the person conducting the fingerprinting (or fingerprinter). It was observed that naming each fingerprint uniquely was inconvenient as there were many RPs. Also, there was no defined logic to naming fingerprints, so this task was left entirely up to the fingerprinter. Critically, the 'location_number' field had no perceptible utility in the application.

The map was conventional (Figure 4.1) and showed walls, windows and rooms without any room names. Hence the sole method to communicate location information was the map. The output of the position estimation algorithms is the position coordinates, which is used by the EricsPoint application to place a red dot on the visual map. Running the application this way resulted in an accuracy of approximately 3-5 metres. This was found to be sufficient for the purpose of a demonstration.

As part of the 'Transition System' algorithm, a 'history_positions' table was created. This table mapped every device running EricsPoint with its recent position estimates and corresponding timestamps. Each device was identified by its MAC address.

4.1.2. **Phase B**

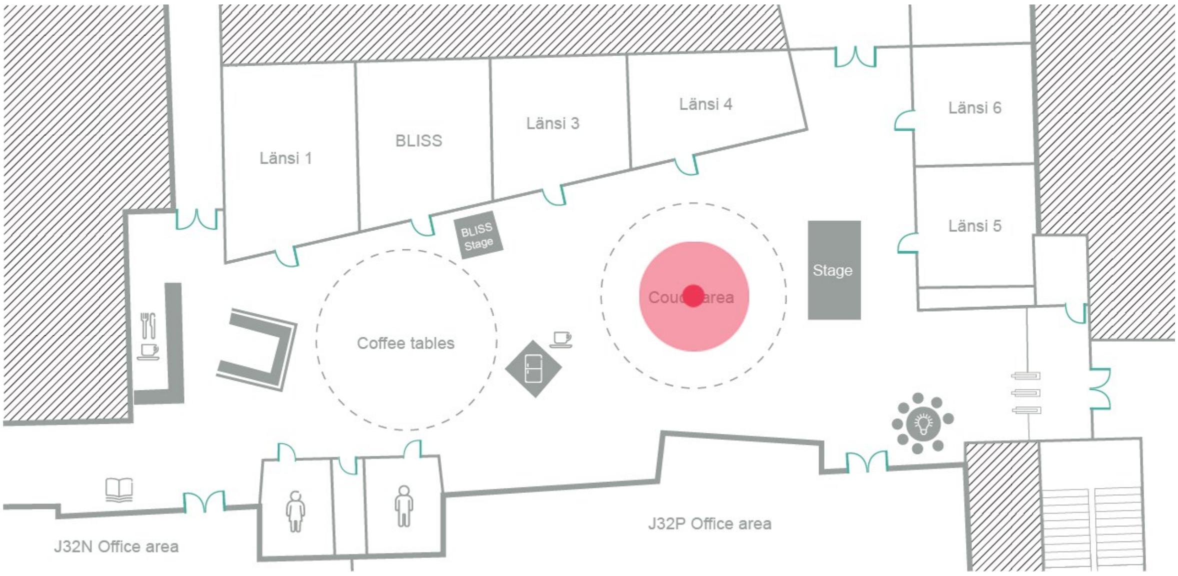


Figure 4.2: Context-based map

The study of location-based services led to the realization that merely displaying the user's position as coordinates on the map is insufficient to build services. It is necessary to associate each RP or set of RPs with contextual information.

Here, the location_number field became valuable. The fingerprinter could name the fingerprint with the context or activity associated with that fingerprint's location. This name - the 'location_number'- provided the necessary contextual information. Points within the coffee area were named as 'coffee_area', those near the library called 'library' and so on.

The history_positions table was now seen as a means to expose real-time location information. Additionally, a 'username' field was added to the EricsPoint Android application. This replaced the MAC address used previously to identify each user.

The webpage was developed at this phase as well. It used this 'history_positions' table to display users' locations on a browser window. It had the additional advantage of being able to show the location of every connected user along with his/her name.

Finally, the map was redrawn and divided into thematic areas of varied sized (Figure 4.2). All points (including RPs) within an area were essentially treated as the same location.

This modified map had twin advantages. Firstly, it decreased the granularity of the map and thus made the system seem more accurate. The user no longer expected to know the exact location, but a rough estimate. Secondly, it clearly showed the context associated with each location. This was helpful to both the fingerprinter and the user (For example: meeting room 1, kitchen, men's room).

4.1.3. **Phase C**

In the final phase with the service prototypes, the map became redundant as a means to communicate location information. Communication in the telecommunications network occurs primarily via voice and text. Thus, in the prototypes it was decided to 'whisper' the 'location_number' into the call. In this way, the visual map interface became obsolete.

A 'whisper' is an external audio stream inserted into the call's media stream, independent of the ongoing conversation. A whisper can be made to be heard by either one or both parties.

In retrospect, the fingerprinting and positioning applications could be modified so as to only use a textual 'location_number' to identify each reference point, thereby simplifying the application immensely.

The final solution is missing many elements from the initial phase, most noticeably the map. The redundancy of the map turned out to be an excellent finding. Some indoor positioning systems like the one described in [47] actually do not even use a map. They identify a location purely by its name. Such a system is far simpler to design. Additionally, it eliminates the need for a map of the indoor area, which is one of the major obstacles in the building and standardization of indoor positioning systems [13] [47].

4.2. **Building blocks of the service prototype**

To understand the environment under which the prototypes were developed, it is necessary to briefly introduce the concepts of IMS, IMS-Application Servers and Ameche, that served as building blocks. Also a description of the GSM gateway is warranted.

4.2.1. IMS and its architecture

The IMS or IP Multimedia Subsystem is a set of technologies, based on the Internet Protocol (IP) [48]. IMS is designed to enable universal access to multimedia services from any terminal in the telecom network, irrespective of it being a mobile device, landline phone or PC.

The IMS is standardized by 3GPP [49] and is conceptually similar to any mobile network technology of today, such as GSM and CDMA, that provides global interoperability between handsets and operators. The IMS was developed primarily for service creation. Hence additionally, the IMS also provides universal service access i.e. seamless and automatic provisioning of the same set of services irrespective of user's whereabouts.

One of the key objectives of IMS is to enable operators to deploy attractive IP-based applications and services. Thus, the IMS was designed to integrate into existing networks, serving as a link between current cellular networks and the internet. This was aimed at enabling operators to expand their role from suppliers of telephony and internet services competing solely on price, to sophisticated enablers and providers of unique services. This would help operators face the challenge of current web-based services and OTT players.

The IMS core network consists of several nodes linked to each other via standardized interfaces. A simplified architectural diagram is shown in Figure 4.3.

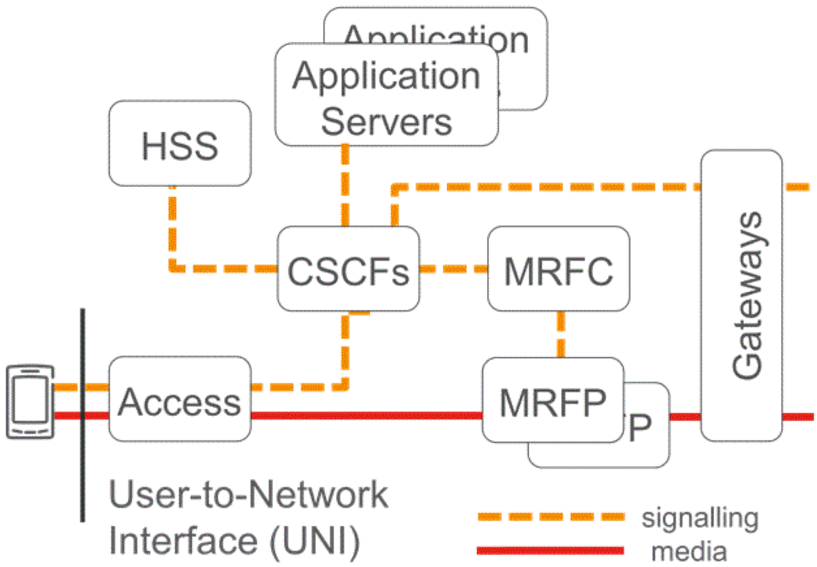


Figure 4.3: Simplified overall IMS architecture

SIP or Session Initiation Protocol is the primary control plane protocol for IMS.

The CSCFs form the core of the control plane, taking care of all the required signalling. CSCF stands for Call Session Control Function.

The HSS or Home Subscriber Server, similar to GSM's HLR (Home Location Register), is the primary subscriber database. It contains subscribers' profiles, services, authentication information, billing information etc.

The Application Servers are where the actual network services are executed. They contain the service logic and have the ability to initiate, modify and terminate sessions.

The MRFC (Media Resources Function Controller) controls media plane resources while the MRFP (Media Resources Function Processor) performs media stream processing and can thus be used in media-related functions such as voicemail, conferencing, translation etc.

An IMS simulator called Ericsson SDS (Service Development Studio) [50] was used in this Thesis as the underlying telephony network. SDS was setup such that it could be accessed via the internal LAN and calls could be made via SIP-based softphones. The internal LAN is accessible wirelessly as well, so softphone clients could be used on smartphones connected to the WiFi as well. A softphone is a software program that can be used to make telephone calls over the internet using a PC or laptop, instead of using dedicated hardware.

4.2.2. **IMS Application Server**

The primary means to develop and deploy applications and services in the IMS is through the IMS-Application Server or IMS-AS (Figure 4.3) [51]. The IMS-AS is a standardized entity in the IMS architecture that hosts specific applications.

An IMS application provides the end-user with a specific service. Multiple applications can be deployed on one IMS-AS and several ASs can be connected to the same domain. IMS applications contain the logic of the service that is to be provided to the user and its interaction with other services. An application server can also access user information from the HSS if required. Multiple Application Servers can be involved in a single session.

Depending on the user profile and filter information available in the HSS, a CSCF triggers the correct application during an incoming call.

An illustrative example of an IMS application is an audio-conference service. A user wishing to join a conference calls a pre-defined conference number or URI (Uniform Resource Identifier) such as 'aud_conf@ericsson.conf.fi'. The user is then asked for the conference id and then a secret PIN, which when entered correctly permits him/her to enter the conference. Otherwise, the entire process repeats.

4.2.3. **Ameche**

Given the IMS design philosophy, capability and interoperability, it provides an ideal environment to implement service exposure today. As explained before, IMS was basically designed for service creation.

However, instead of creating and deploying independent and individual services, a platform enabling easy service creation would be a better approach [4]. A platform that exposes the media and control plane information through easy-to-use APIs would enable developers to create applications without worrying about the complexity of the underlying signalling and protocols. An example of such a platform is Tropo's Ameche Application Server [8], which was used in this Thesis to create the prototype services. It is an all-software platform designed to sit atop and integrate with the core telecommunications network.

The Ameche platform provides a fully integrated stack where applications can be created, tested and deployed. Additionally, since Ameche was developed using internet and web technologies, its applications have the capability to interact with other web services as well.

The Ameche platform provides APIs for functions such as call recording, inserting announcements into a call, call redirecting etc. through which the application can interact with the call media and provide additional services within a phone call. Being network-based, it has the additional advantage of being able to provide services on any handset and mobile device, thus eliminating the need to explicitly download an application for every service.

4.2.4. **GSM Gateway**

Another piece of hardware that was used while implementing the service prototype is the VoxStack GSM gateway [52]. The exact model used in this Thesis was the OpenVox VoxStack Series GSM Gateway, VS-GW1200-4G. The gateway enables calls to be made from a softphone to a normal GSM phone and vice versa, thus acting as a link between IMS and GSM networks. The gateway connects to the IP network via an Ethernet cable and can be configured to connect to any IMS/SIP server in that network. It can also be fitted with a SIM card, through which it can make calls to the GSM network.

4.3. **Prototype services**

Initially, the Ameche application server was connected to the IMS simulator and calls were made via softphones running on a laptop PC. However, with this setup the user experience and usability of the prototype was dissimilar to a possible product on the market. Hence, softphone clients on smartphones were used. Tests were carried out with Linphone [53] and Sipdroid [54] in particular.

In this case the user would have to install the softphone client on his/her smartphone or use a test device. Ideally since the application runs over the network, users should be able to use their own phones to use the service. Hence a GSM gateway was used (Figure 4.4).

In practice, a call is made from a softphone to a normal GSM phone number, by calling to

sip: <GSM-phone-number-with-international-code>@<IP-address-of-GSM-gateway>

The user then receives the call to his/her personal phone. Thus the user experiences the call as though there is an application running in the network.

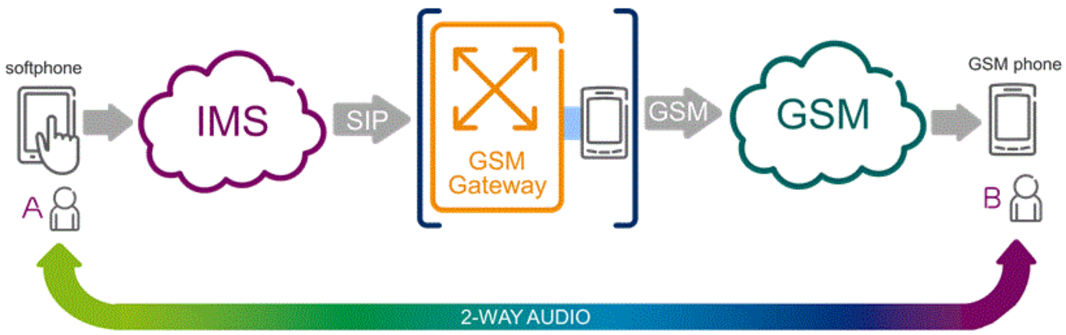


Figure 4.4: Role of GSM gateway in the service prototype

Overall, the significant stages in the development of the prototype were:

1. The Indoor Positioning System, EricsPoint was built using a visual map. Positions were stored as <X, Y> coordinates, 'location_number' was used to identify RPs and 'history_positions' table was used in the 'Transition System' algorithm.

2. Ameche was found to be capable of querying the 'history_positions' database table.

3. The map was redrawn and 'location_number' was now used to define the theme/activity associated with a set of reference points. 'Location_number' was whispered into the call to the concerned party.

4. The visual map became obsolete. Positioning application was now running in the background. EricsPoint could be then simplified to just send WiFi scans and not receive any info from the server at all.

5. The GSM gateway was used in the prototype service for user testing.

Selecting a prototype service to implement and test was challenging from both technical and user experience perspectives. The service must be easy to explain and understand. Feedback is valuable when the application is clearly understood and the user is focused on the potential service and not the technicalities.

Most importantly, the service must be based on a use case that the user can relate to. It should not be a purely technical demonstration. It must evoke an emotion, such that the user would consider it useful in his/her life.

Some of the prototypes considered were:

- Calling a place (for example, meeting room A) and getting connected to one person in that room.

- Finding an unreserved meeting room nearest to the caller or callee or both.

- Calling all of the user's teammates outside of the room in which the user is located.

Finally, the two chosen prototypes were Friend Finder and Exhibition Helper. The other candidate prototypes listed above would not have been very difficult to implement.

4.3.1. **Friend Finder**

Figure 4.5: Friend Finder service prototype

A popular and easy to understand use case is a 'Friend Finder' service [21] [41]. In a normal call, one of the first questions that is usually asked is 'Where are you?' Even when one is familiar with the surroundings, it is sometimes difficult to communicate one's location properly and with sufficient accuracy.

One solution is to use a smartphone tracking application with a map. This application would keep track of a user's location in real time and enable the other user to access this information.

However this brings us back to the problem of needing to download an application on the phone. More importantly, there is no call between the parties and also there is no operator involvement.

Another way to communicate location is via the audio interface as a whisper during the call. This is made possible via an Ameche API [8]. This is in keeping with the learnings gained from the study of location-based services.

With all this in mind, the application works such that there exists a call between 2 parties in which the users are speaking to each other. At any point during the call, the called party B can dial '1' on his/her own GSM handset's dial pad and the caller's location is whispered to the called party (Figure 4.5).

The called party can dial '1' any number of times during the call and the current location of the caller is whispered.

A probable scenario is when the calling party (A) arrives at a new location that the called party (B) is familiar with. For example, when a user is at the airport and calls airport security to help him/her navigate. During the call, the security personnel give the lost passenger directions to reach a certain gate. While on call, they can dial '1' periodically to check that the passenger is headed in the right direction.

4.3.2. Exhibition helper

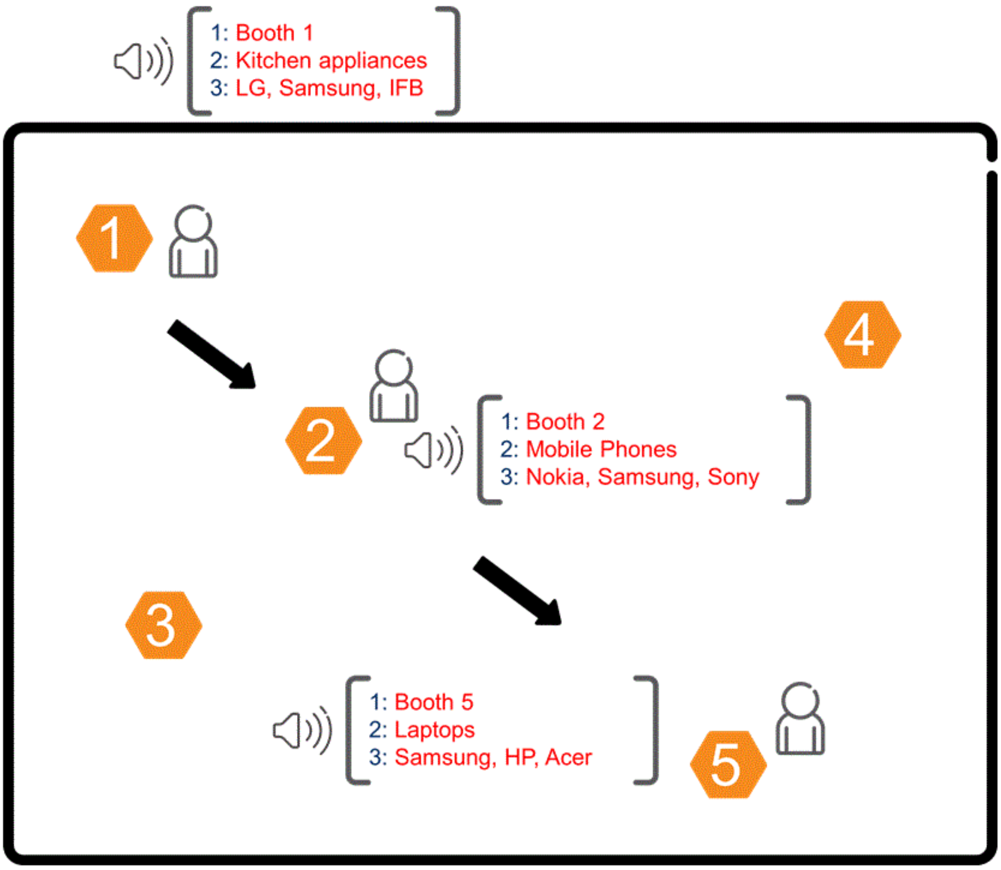


Figure 4.6: Exhibition Helper service prototype

The scenario is such that a user is moving about an exhibition venue. The personnel are either busy with other visitors or the user does not wish to speak with the booth personnel.

In this situation the prototype works such that, as the user is walking in the exhibition space, he/she is tracked by the indoor positioning system. If the service is provisioned for this user, he/she receives a call from a helpline number. During the call he presses '1' to know the booth ID of the nearest booth, '2' to know applicable industry and '3' to be whispered the companies showcasing their products (Figure 4.6).

A parallel situation could be envisioned for hospitals where doctors could get patient data and in furniture stores like IKEA, to get information on prices of products.

4.4. System Setup

In both the prototype location-based services, the basic overall system architecture is similar. The indoor positioning system runs in the background, tracking the location of the user in question. In the 'Friend Finder' service the tracked user is the caller, while the callee is tracked in the 'Exhibition Helper' demo.

An Ameche application running on the IMS core is triggered when the call connects and waits for the user input. When the user presses '1' on his/her dial pad, the Ameche application queries the 'history_positions' database for the last known location of the user. As described before, this location (called 'location_number') actually refers to the theme or activity related to that position. This 'location_number' is whispered into the call.

Now, since the location is now known, the application can be enhanced to include more information about that specific location. This information can be whispered on another trigger, for example by pressing '2' or '3'. This is done in the exhibition app.

Figure 4.7 presents the overall system setup. The GSM gateway has been omitted from this diagram for simplicity.

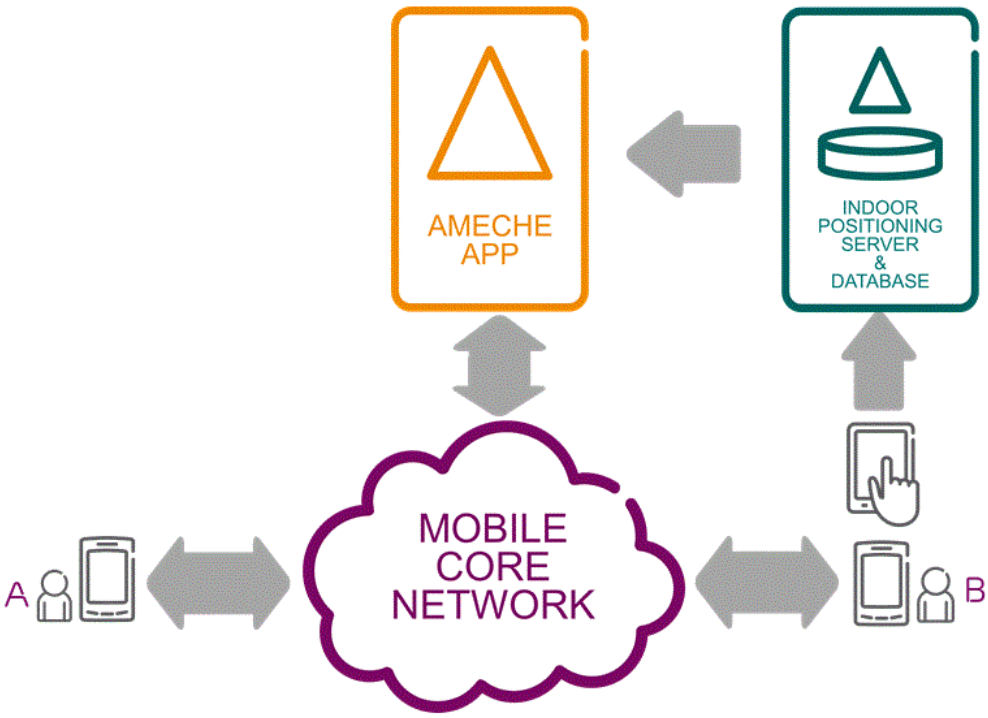


Figure 4.7: Service prototype architecture

4.5. **Test environment**

The test environment for both prototypes was chosen to be Länsitori, in Ericsson's site in Jorvas, Finland as the indoor positioning system, EricsPoint was already deployed there.

For the 'Friend-Finder' service prototype, one volunteer walked around Länsitori, with the Android device. The device had the EricsPoint application running in the background. The callee was in another area and helped the volunteer navigate around Länsitori.

The 'Exhibition-Helper' service was demonstrated during Ericsson's NomadicLab event held in Länsitori. During the event, there were several booths exhibiting NomadicLabs' research findings.

CHAPTER 5

USER TESTS AND RESULTS

Recent times have seen a rapid and vast adoption of mobile and web services. From the usage patterns, it is apparent that consumers are apathetic to the technology behind a service [29]. Thus a service prototype should be evaluated from an end-user perspective rather than from a technology standpoint. Hence, a user test was carried out with the ’Friend Finder’ application. This chapter discusses its results and the user feedback received.

5.1. Conditions of the test

The user tests were carried out using the ‘Friend Finder’ service prototype with 6 volunteers. The users were seated in the café area of Länsitori, while the conductor of the test was at a different location in the test area such that the two could not see each other. The conductor had the tablet with EricsPoint running.

The use-case is that the conductor is lost in the test area and needs to be guided to the café area. The user is familiar with the test area. Hence the conductor calls the user’s handset. Once the call is connected, the two can speak to each other as in a normal phone call. At any time during the call, the user can dial ‘1’ on his/her handset and the conductor’s location will be announced into the call. Using the location whispers and his/her own familiarity of the test area, the user converses with the author and guides him to the café area. In total 6 users were interviewed.

The purpose of the user tests was to get feedback on the idea and implementation of the service prototype. In the course of these tests, the users made several valid and useful recommendations for improvements. Their comments are discussed in this chapter. However, the recommendations are not implemented as part of this Thesis work and left for future work.

5.2. User test questions

After the completion of the test, users were asked the following questions to get an idea of their experience with the service. Their responses were noted and based on them a SWOT analysis was done.

1) What was your experience with this service?
2) How did you feel about getting information during a phone call?
3) How would you compare this experience with having a visual map?
4) Would you use this type of service? In which scenario?
5) Would you recommend this service to someone you know?

5.3. User test results

There were several common themes that emerged from users' comments. These comments speak about user perception towards both the idea of the 'Friend Finder' service as well as the actual execution of the prototype. User comments towards the service have been categorized into the strengths, weaknesses, opportunities and threats, so as to aid the final SWOT analysis. The SWOT matrix was chosen as the analysis tool because it is widely used and easy to understand.

Users noted that the service was simple and easy to use. Most found that receiving location information during a phone call, without having to hold another device or switching between applications was a clear strength. Also, the user decides when he/she wants the information. Some compared the service to the familiar car navigation system. Several users felt that the service made it unnecessary to ask the calling party specifically for landmarks during the call. When asked if a service needed to be accompanied with a visual map, most said that if the place was familiar, the map was unnecessary. Finally, all users declared that they would recommend this service to an acquaintance.

Coming to the weaknesses, users noted that familiarity with specific places is not very common and that along with names of places, landmarks would be needed as well. Several users complained about the voice quality, the background noise and the accent of the whispers. Some said that the experience of the service would be enhanced if some sort of visual aid was provided such as a dynamic map showing the lost user's location or even a static map of the area. Lastly, most users felt that the context of this particular use case was narrow, i.e. it would only be helpful in cases where the calling party is lost and the called party is well acquainted with the area.

There were several comments that could be seen as opportunities for the service concept. Users felt that this service would be helpful while travelling, to gather or guide people to a particular location. Some suggested that location could be accompanied with information about nearby points of interest, such as restaurants or cafes. One user proposed an accompanying 'Hot or Cold' game that would signal to the user if the destination is getting nearer or farther. Several users felt that this service would be useful to aid friends who are lost either outdoors or indoors in a large shopping mall or exhibition area when looking for a particular point of interest. One consistent suggestion was that the service could be improved by including directional information along with the position. Few pointed out that naming of the positions was critical, especially in the interest of advertising, for example, 'You are next to Pizza Hut' as opposed to 'You are in front of Starbucks'.

There were many aspects about the service, pointed out by users that could be seen as threats. Some said that the service would be useful in a new place, but that a map would still be needed. One common feedback from users was that in today's smartphones, going to the dial pad screen while in a call is not very straightforward. So the service could be triggered via an external button on the smartphone or via voice commands. Some who praised the service mentioned that, the service would be useful only during the calling party's first visit to a place, when he/she is totally alien to it. One person claimed that sending the map to the lost user would be a simpler solution to the entire problem. Many stressed on the accuracy of the system and pointed out that accuracy was critical to the usability of the service.

5.3.1. **SWOT Matrix**

Based on the user test results, a SWOT analysis was done and the results were tabulated (Table 5.1)

STRENGTHS	WEAKNESSES
• There was no need to switch between multiple apps • Information was available on demand • The service was easy to use	• Familiarity with a location is uncommon • Poor call quality • There was no visual map • The context of the use-case was very narrow
OPPORTUNITIES	**THREATS**
• This service will be helpful while travelling • Names of places could help in advertising • Directional information would be additionally valuable • A 'Hot & Cold' game could be included • Information on nearby places of interest would make the service more useful	• It is difficult to reach the dial pad during a call in smartphones • Sending the map file might be a better solution • Positioning must necessarily be accurate and reliable

Table 5.1: SWOT Matrix based on user tests

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

In this chapter, the results of this Thesis are presented. Some possibilities for future work in related areas are also discussed.

6.1. Conclusions

One of the primary results of this Thesis is that location information can be organized into several layers and that each application must choose which layer(s) to get relevant information from. Also, a person's location can be used to determine his/her activity or context.

A visual map is not the only medium of representing location information. Visual maps are often difficult to obtain and also, navigating with a visual map is not always straightforward. These disadvantages are more pronounced in indoor environments.

Location information is dynamic and contextual, with relevance changing from application to application. Maps need not always scale. Location can be communicated not just with a dot on a visual map but alternately with plain text, a voice or sound or even images. Also, merely providing location information is of little value. Positioning capability must be seen as an enabler that enhances existing services and gives rise to new independent ones.

Another important result is with regard to location accuracy. Not every application requires a high level of location accuracy. With a proper policy and structure, privacy concerns can be mitigated and also a much wider range of location-based services can be envisaged.

A survey of current systems shows that there exist several techniques, technologies and algorithms that can be used to build indoor positioning systems. Each approach has its own pros and cons. It is improbable that one single technology -such GPS for outdoor positioning- will overpower all other systems. It is most likely that commercially successful positioning systems will be based on a combination of technologies.

The economic value of service exposure and the ecosystem approach is undeniable. However, this approach requires a fundamental change in the way operators view their customers, content providers as well as other operators. A relationship also needs to be built with developers.

6.2. **Future Work**

An interesting research area would be to study the relation between positioning accuracy and network parameters such as coverage, throughput and quality of service (QoS). As they exist today, positioning systems are applications built atop the existing radio access network. Radio access networks are optimized for coverage, throughput and QoS among other key performance indicators (KPIs). Positioning services of today are technologically nascent. They are limited in their scope, reach and economic potential. However, as they become more important, positioning accuracy could become one of the parameters that determine network design.

As telecommunications networks are evolving, they are becoming flatter with intelligence moving more and more towards the edges, near the user. Positioning is one service that could benefit immensely if more data and information from radio access networks is exposed via APIs. Other areas such as security, banking, emergency services and even network optimization could improve with this trend. This will further complicate network design.

This Thesis discusses service exposure from the core network perspective. Current positioning algorithms utilize RSS and user information obtained from the handset. These could be further improved if APIs that exposed radio-access information from the base station or AP were available. If such APIs existed and they provided access to RSS and other relevant data, an independent and fully network-based positioning system could be built from them. Furthermore, these APIs would also be useful in radio planning and network optimization.

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