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„Integration of Indoor Location-based Services to an University Environment“

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Declaration of Authorship

I, Barbaros ÖZDEMIR, BSc, declare that this thesis titled, "Integration of Indoor Location-based Services to an University Environment" and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed:

Date:

UNIVERSITY OF VIENNA

Abstract

Faculty of Computer Science
Workflow Systems and Technologies

Master of Science

Integration of Indoor Location-based Services to an University Environment

by Barbaros ÖZDEMIR, BSc

Location-based services enable improvements in processes not only as a tool providing assistance for users by extending their knowledge on areal information and ongoing activities close-by their whereabouts but also as a sensor collecting spatiotemporal data on users to allow application of big data analytics which uncovers correlations in users' behavior in different circumstances.

The positioning of users is critical for location-based services to function properly. The techniques and the required accuracy of positioning varies depending on specifications of the deployed service. I.e. services designed for outdoor usage may leverage positioning techniques which do not perform as well indoors. Furthermore outdoor location-based services may require lower level of precision compared to services designed for indoor usage. As indoor positioning has different requirements in terms of technology unlike outdoor positioning there is no ubiquitous solution which can be utilized.

This study embodies the design and implementation of an experimental system which contains both the development of an indoor positioning algorithm and the implementation of indoor location-based services and analytics tools by using open-source technologies. The algorithm implementation consists of a simulation program, a mobile device- and a server-side application. The management of services occurs on a website through an Administration Panel.

The proposed indoor positioning technique is a Wireless Local Area Network (i.e. WiFi) Fingerprinting algorithm based on Received Signal Strength and is designed to dynamically adapt itself to different environments. It also provides a self maintenance feature to limit the requirement of interventions for correction of positioning errors after deployment.

As the proposed system has a modular architecture it can theoretically be extended to cover an unlimited number of indoor locations for positioning and to supply them with customized indoor location-based services.

UNIVERSITÄT WIEN

Zusammenfassung

Fakultät für Informatik
Workflow Systems and Technologies

Master of Science

Integration von Indoor Ortsbasierten Diensten in eine Universitätsumgebung

von Barbaros Özdemir, BSc

Ortsbasierte Dienste ermöglichen die Verbesserung von Prozessen, indem sie die Benutzer mit Orts- und Ereignisinformationen in deren unmittelbaren Nähe unterstützen. Außerdem werden sie als ein Sensor zum Wahrnehmen von Ort-Zeit Daten von Benutzern verwendet. Letzteres ermöglicht die Anwendung von Datenanalyseverfahren, um Korrelationen im Benutzerverhalten aufzudecken.

Die Ortung von Benutzern ist Voraussetzung für die Funktion Ortsbasierter Dienste. Die Methoden und die benötigte Korrektheit der Ortung variiert basierend auf den Spezifikationen der eingesetzten Dienste. Die Dienste, die für die Outdoor-Ortung gedacht sind, nutzen Methoden, die im Indoorbereich eine schlechtere Leistung erbringen. Weiterhin erfordern Outdoor Ortsbasierte Dienste im Vergleich zu Indoor Ortsbasierten Diensten eine niedrigere Ortungsgenauigkeit. Da Indoor-Ortung verschiedene Anforderungen im Sinne der verwendeten Technologien als Outdoor-Ortung hat, existiert dafür zurzeit keine universale Lösung.

Diese Studie enthält das Design und die Implementierung eines experimentellen Systems mit Open-Source Produkten. Sie umfasst sowohl die Entwicklung eines Indoor-Ortungs-Algorithmus als auch die Implementierung Indoor Ortsbasierter Dienste und Analysefunktionen. Die Implementierung des Algorithmus besteht aus einem Simulationsprogramm, einer Mobile und einer serverbasierten Anwendung. Die Verwaltung der Dienste erfolgt über eine Webseite, welche die Aufgaben und Funktionalitäten einer Administrationsschnittstelle realisiert.

Die vorgeschlagene Indoor Ortungsmethode ist ein Wireless Local Area Network Fingerprinting Algorithmus basierend auf die empfangene Signalstärke. Sie ist so entworfen, dass sie sich an unterschiedliche Umgebungen dynamisch anpassen kann. Sie bietet desweiteren eine Selbstwartungsfunktion, welche die Notwendigkeit manueller Eingriffe zur Korrektur der Ortung nach Start des Einsatzes begrenzt.

Das vorgeschlagene System hat eine modulare Architektur. Dadurch kann es theoretisch so erweitert werden, dass es eine unbegrenzte Anzahl von Indoor Orten beinhalten und diese mit maßgeschneiderten Indoor Ortsbasierten Diensten unterstützen kann.

Acknowledgements

I have always been interested in solving real-world problems. When I started my Bachelor study at the University of Vienna it didn't took me long to realize that finding the class room in the main building was a challenging task for most of the students in the freshman year. I found it also astonishing that most of the message exchange with my friends was about our whereabouts even though we were in the same building or the next. As a future Computer Scientists at that point I asked myself what we could do to solve this challenge and started to read the few research papers on indoor positioning and wrote some experimental programs to test different approaches.

The task was fairly doting. The solution should work on all devices, thus it needed to be ubiquitous. It should not have a negative impact on user's daily operations in terms of battery usage and computing power. It should also be easily deployable and extensible.

It was the dawn of location-based services and indoor positioning was an emerging research field. This was the start of my adventure fueled with my passion for creating systems that hasn't existed before.

This thesis is a tribute to that adventure not necessarily to mark its end but to be a milestone which hopefully might help as a small beacon to those who are working on the same challenge.

I would like to express my sincere gratitude to Prof. Stefanie Rinderle-Ma for her guidance, support and encouragement throughout this thesis, which marks that milestone.

I would also like to thank all my friends who supported me with their feedback's during the development phase and shared their precious time for the evaluation of the final implementation. Special thanks goes to Dr. Janet Wissuwa for proofreading this thesis.

Last but not least i would like to thank my parents for their support and their understanding in stressful times during completion of this study.

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List of Abbreviations

AI	**A**rtificial **I**ntelligence
API	**A**pplication **P**rogramming **I**nterface
ATM	**A**utomated **T**eller **M**achine
BLE	**B**luetooth **L**ow **E**nergy
CBECS	**C**ommercial **B**uilding **E**energy **C**consumption **S**urvey
CPU	**C**entral **P**rocessing **U**nit
CSS	**C**ascading **S**tyle **S**heets
CEWebS	**C**ooperative **E**nvironment **Web S**ervices
CSV	**C**omma **S**eperated **V**alues
D	**D**imension
dBm	**d**eci**B**el-**m**illiwatts
deg	**deg**ree
EIA	U.S. **E**nergy **I**nformation **A**dministration
ER	**E**ntity-**R**elationship
FP	**F**inger**P**rinting
g	Earth's **g**ravitational force
GCM	**G**oogle **C**loud **M**essaging
GHz	**G**iga **H**ert**z**
GiB	**Gi**ga **B**yte
GLONASS	**GL**obal **O**rbiting **NA**vigation **S**atallite **S**ystem
GPS	**G**lobal **P**ositioning **S**ystem
HTML	**H**yper **T**ext **M**arkup **L**anguage
HTTP	**H**yper **T**ext **T**ransfer **P**rotocol
ID	**ID**entifier
IDE	**I**ntegrated **D**evelopment **E**nvironment
IMAP	**I**nternet **M**essage **A**ccess **P**rotocol
IPS	**I**ndoor **P**ositioning **S**ystem
JDBC	**J**ava **D**ata**B**ase **C**onnectivity
LBS	**L**ocation **B**ased **S**ervices
m	**m**eter
MB	**M**ega **B**yte
MAC	**M**edia **A**ccess **C**ontrol
min	**min**ute
NA	**N**ot **A**vailable
NFC	**N**ear **F**ield **C**ommunication
PHP	**H**ypertext **P**re**P**rocessor
PNG	**P**ortable **N**etwork **G**raphics
QR	**Q**uick **R**esponse
RAM	**R**andom **A**ccess **M**emory
REST	**RE**presentational **S**tate **T**ransfer
RFID	**R**adio **F**requency **ID**entification

RSS	**R**eceived **S**ignal **S**trength
RSSI	**R**eceived **S**ignal **S**trength **I**denticator
s	**s**econd
SQL	**S**tractured **Q**uery **L**anguage
T	**T**esla
TDOA	**T**ime **D**ifference **O**f **A**rrival
TOA	**T**ime **O**f **A**rrival
URL	**U**nified **R**esource **L**ocator
UWB	**U**ltra **W**ide **B**and
UWB-IR	**U**ltra **W**ide **B**and-**I**mpuls **R**adio
WBA	**W**ireless **B**roadband **A**llience
WLAN	**W**ireless **L**ocal **A**rea **N**etwork
XML	E**X**tensible **M**arkup **L**anguage
ZID	**Z**entraler **I**nformatik**D**ienst der Universität Wien

1 Introduction

This chapter contains a basic introduction to indoor positioning and location-based services. It discusses the challenges that need to be handled by techniques designated as candidates for indoor positioning. It also encompasses the aim and expected results of this study and provides an overview on its structure.

Indoor positioning is about locating objects inside closed environments by e.g. utilizing sensors on mobile devices and if applicable references from the surrounding. The quality of positioning is then evaluated based on the attributes accuracy and precision. Throughout this study the term "accuracy" is used to indicate the level of correctness of the calculated position and the term "precision" to indicate the level of detail position data contains. As a rule of thumb decrease in precision is expected to increase accuracy.

1.1 Motivation

According to the study of Michaels (2012) not only the amount of large infrastructures continue to increase and but also the area these buildings contain expands as shown in Fig. 1.1.

The increasing size of structures results in higher complexity of their architecture which makes navigation more difficult for its visitors. Large structures are due to high number of services they offer also challenging for conducting analysis on i.e. visitor flows and utilization pattern of different areas in the building. These analysis are critical to optimize and orchestrate processes inside structures to ensure steady run of their services.

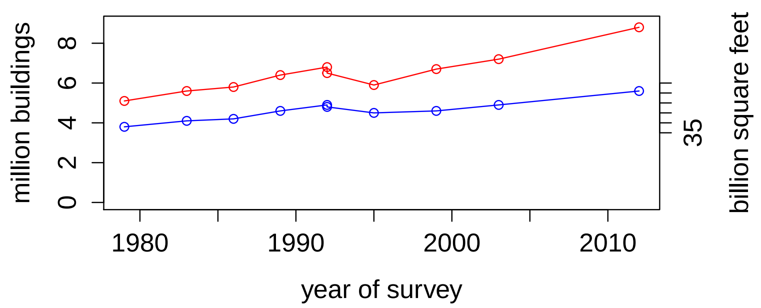

FIGURE 1.1: EIA's 2012 Commercial Buildings Energy Consumption Survey result compiled from Michaels (2012) (blue - number of buildings, red - floor space in square feet).

The lack of real-time monitoring tools for processes taking place indoors, where human spatiotemporal behavior effects the run-time of the process, the lack of tools for collecting data on retail agglomeration and the requirement for undertaking measures regarding problematic navigation inside large buildings are the main arguments for this study's motivation.

1.2 Problem Statement

The challenge in indoor positioning is the development of an ubiquitous technique performing in a foreseeable range of accuracy and precision in every closed environment.

As the so called "Personal Zone" of humans have been calculated in Hall (1966) between 45 cm and 120 cm the targeted precision of indoor positioning techniques is to be set ideally as 45 cm.

The horizontal precision provided by existing ubiquitous positioning techniques are for GPS according to *GPS Standard Positioning Service (SPS) Performance Standard (4th Edition)* (2008) three meters and for GLONASS according to *Information analytical centre of GLONASS and GPS controlling* (2016) ten meters. Additionally as stated in Pahlavan and Li (2002) these techniques are not designed to work in closed environments. Thus their performance decreases when there is no line of sight between the receiver and the satellites.

As also stated in Costilla-Reyes and Namuduri (2014) there is no ubiquitous solution published yet for indoor positioning.

1.3 Aim of the Work

The aim of this study is the development of a platform which is capable of showing visitors behavior inside buildings through analytics features without requiring the installation of additional hardware to extend the existing WLAN infrastructure.

The platform is also enabled to create messages which are send to their recipients once the addressed user stands in the designated location during the given time interval. The messaging service is designed in a way that it can be extended with minimal effort simply by adding new modules and linking them to the platform.

The development of a mobile application with indoor positioning capability to support the services feature of the platform is also a critical objective of this study. The implemented indoor positioning algorithm is aimed to have a precision of 3.5 m, which is determined in Hall (1966) as the distance of the so called "Social Zone" in human interactions. Furthermore the design of the algorithm contains a self-maintenance feature making the algorithm adaptable to the changes in the environment.

1.4 Structure of the Work

This thesis consists of seven research chapters. The relationship between each research chapter and the handling of topics is visualized in Fig. 1.2 where each group of associated chapters is colored with a different density of Grey.

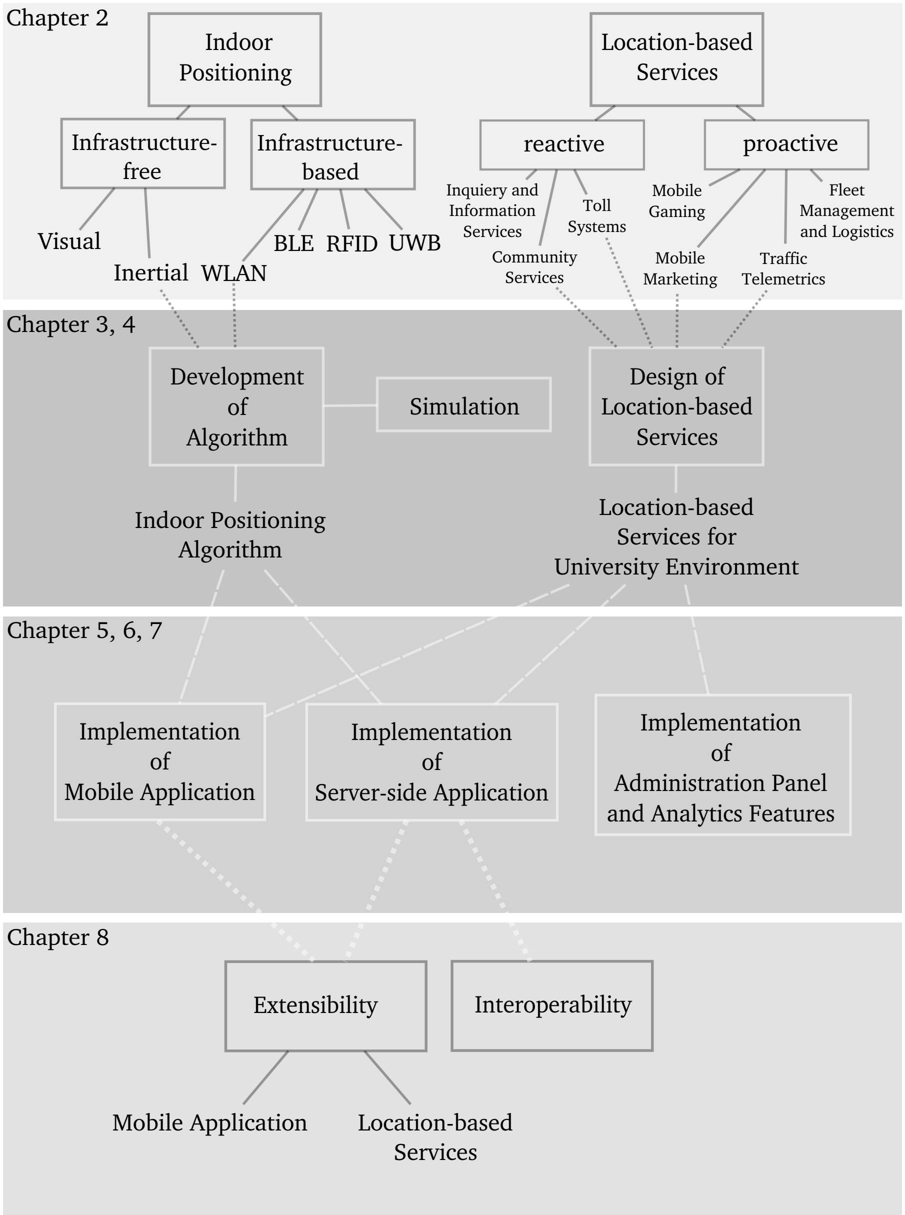

FIGURE 1.2: Contents of each chapter and the inter-chapter relation of discussed subjects.

Chapter 2 provides an overview on techniques for indoor positioning and their specifications. It also compares them according to their performance and requirement of maintenance. The main objective of this chapter is to discuss all known main-stream technologies which can be utilized to enable indoor positioning. Chapter 2 provides also an introduction on location-based services and discusses them in context of the university environment. The names of these location-based services are used throughout this thesis as a guideline to indicate which services are considered for implementation, how they are interpreted and which parts of the implementation is relevant to which location-based service.

Chapter 3 provides information on the developed WLAN Fingerprinting algorithm in this study and its evaluation using a simulation program. As shown in Fig. 1.2 the developed algorithm within this study utilizes only two of the technologies described in Chapter 2; Inertial and WLAN. This chapter also contains the accuracy and precision of the developed algorithm and its detailed description. Although Chapter 3 contains an evaluation of the algorithm's performance it is important to note that the simulation program which conducts the evaluation is a part of the algorithm and the algorithm works according to best-effort principle (i.e. generates best performing signal map).

Chapter 4 discusses the design of location-based services which are considered suitable for implementation at the university environment within this study. As shown in Fig. 1.2 only four of the initially introduced services from Chapter 2 are selected as the suitable for implementation. This chapter describes which criteria was utilized for selection of the location-based services and how each location-based service is interpreted for implementation.

In Fig. 1.2 are the results shown which are created at the end of Chapter 3 and Chapter 4 and how they are associated to the components of the implementation.

Chapters 5, 6 and 7 discusses the implementation in regard to its architecture, the algorithm from Chapter 3 and the selected location-based service features from Chapter 4. Please note that the names of in Chapter 2 introduced location-based services are used throughout this thesis to help the reader to understand the relationship between the services, their interpretation and their implementation.

Chapter 8 provides information on extensibility and interoperability of the proposed system.

1.5 About the Implementation

The implementation consists of three parts; a server-side application, a website and a mobile application. The code has been published on the project homepage. The project homepage is located under following URL:
`http://ilbs.cs.univie.ac.at/`

The mobile application for devices running Android Operating System can be downloaded from the Google Play Store through following URL:
`https://play.google.com/store/apps/details?id=at.ac.univie.cs.ilbs`

The video demonstrating positioning performance can be viewed under following URL: `https://youtu.be/CwEp2NzYlwA`

All schema have been drawn with the program "Inkscape" and all plots/heatmaps have been generated with the program "R". Exceptions are mentioned in the caption.

2 State of the Art

This chapter provides an introduction to the existing indoor positioning techniques. It also discusses the location-based services and their potential application scenarios.

Although the aim of this study lies primarily in the development of an indoor positioning technique which does not require any additional hardware to the existing WLAN infrastructure. This chapter discusses also the techniques which were not planned to be used in this study but were considered and compares them regarding their performance, implementation and maintenance costs.

2.1 Indoor Positioning

Indoor positioning is the term used to describe the technologies applied for location estimation of people and items in closed environment.

As stated in Lymberopoulos et al. (2015) the technologies used for indoor positioning can be divided in two groups; "infrastructure-based" and "infrastructure-free".

2.1.1 Infrastructure-free IPS

Infrastructure-free positioning systems are utilized to calculate position relative to the starting point, where the device was positioned at the beginning of movement i.e. initial position. The advantage of inertial positioning algorithms is that they are autonomous and do not require any infrastructure for computing the location once supplied with initial position information as mentioned in Goldenberg (2006). The calibration of the initial position information is required to estimate device's absolute position. This is why inertial positioning algorithms have the necessity to be combined with an infrastructure-dependent algorithm for indoor positioning or GPS/GLONASS.

An alternative to the inertial navigation is the visual navigation which works in a similar fashion to a human recognizing the position by comparing elements in the surrounding with previous knowledge of that area.

Inertial

The inertial navigation is conducted based on the data from compass, gyroscope and accelerometer sensors.

An accelerometer sensor can measure acceleration force which it is exposed to along a given axis. The accelerometer sensor utilized in Android devices read acceleration forces along x, y and z axis where x and y are horizontal and z is vertical as stated in Milette and Stroud (2012). A relative to the earth stationary Android device lying on a surface without an incline and standing at sea level reads on z axis a value around 9.807 m/s^2 which equals to the earths gravitation force. The x and y accelerometer of the same device read a value around 0 m/s^2. An accelerometer employed in Android devices can measure acceleration at rates of up to ±16 g as mentioned in *LSM330DLC iNEMO inertial module: 3D accelerometer and 3D gyroscope* (2012).

As a compass a magnetic field sensor is utilized which measures the magnetic flux density around it caused by an electronic device or a magnetized item. The magnetic field sensor in Android devices takes advantage of Hall sensor technology and can measure magnetic flux in x, y and z axis with a sensitivity of ±4900 μT as mentioned in *AK09911 3-axis Electronic Compass* (2014). When computing the direction based on the earths magnetic field there are two effects to take into consideration i.e. magnetic inclination and magnetic declination. The term magnetic inclination implies that the magnetic field of the earth is not horizontal to its surface at all locations. The reason for employing a 3-axis magnetic field sensor as a compass is magnetic inclination because a 3-axis magnetic field sensor does not require to be horizontal to the magnetic field in order to read it. The term magnetic declination implies that the magnetic north of the earth does not show the true north. Thus data from a magnetic field sensor needs to be calibrated with the help of the GPS position.

As gyroscope an angular velocity sensor is utilized which measures its acceleration while rotating by taking advantage of the Coriolis effect. A gyroscope employed in Android devices can measure angular acceleration at rates of up to ±2000 deg/s as mentioned in *LSM330DLC iNEMO inertial module: 3D accelerometer and 3D gyroscope* (2012).

According to *Accelerometer Terminology Guide* (2007) the sensor data has a limited resolution and is subject to noises which are described by Schloss (1993) as any undesired signal. The accelerometer sensor readings captured during a four seconds walk are shown in Fig. 2.1.

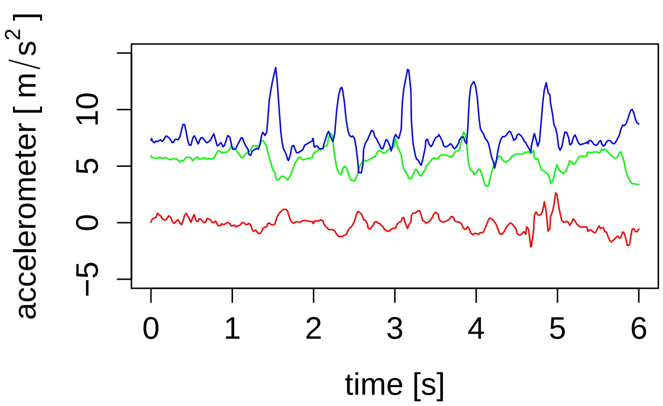

FIGURE 2.1: Log of the Accelerometer Sensor (Sensor coloring schema; x-axis: red, y-axis: green, z-axis: blue).

Each spike of the blue line representing the z-axis between 1st and 5th seconds are generated by the vibration at one of the five steps. A similar pattern can be recognized in y-axis. The reason for this is that the measurement was made on a tablet device hold with one hand (left) which was rolling at each step temporarily to the right. The data on the x-axis which indicates the linear acceleration of the movement lacks a similar pattern as seen in y- and z-axis, thus making its interpretation challenging. The data measured between 0th and 1st seconds are noises.

Noise from accelerometer and gyroscope sensors can be misinterpreted as movements. This misinterpretation causes drifts i.e. bias errors in calculated position. The inertial navigation does not utilize a calibration mechanism. As a result a bias error occurred during run time is carried throughout the calculation until the absolute position is calibrated again. To prevent the bias error developed during inertial navigation (i.e. sensor fusion) an algorithm is required to utilize methods such as the Kalman filter for noise elimination as suggested in Sabatini (2006).

It is possible to reduce the error of each sensor and to create a reliable basis for the computation of movement direction and distance through a sensor fusion algorithm as suggested in Sachs (2010) .

Visual

The visual indoor positioning can be conducted with ego-motion systems computing their location based on 3D building models. The depth information is gained through synthetic stereo vision as stated in Mautz and Tilch (2011) or using a 3D camera with a range of up to four meters as stated in *Intel® RealSense^{TM} Data Ranges* (2015), and utilized in experimental mobile devices as stated in *Project Tango* (2015).

The challenge in visual indoor positioning is that the latest 3D model of the building is required to be available to the device prior to the computation. It is also critical that the employed algorithm has the ability to distinguish obstacles created by temporarily placed items and human presence from the building's infrastructure.

2.1.2 Infrastructure-dependent IPS

Infrastructure-dependent positioning systems are based on radio-signal reckoning. The infrastructure can be utilized as multiple reference points or a unanimous sensor. This study discusses the technologies (except UWB) from the perspective where they are put in use as reference points and the positioning is conducted on client-side in a similar fashion to GPS. As dead-reckoning is conducted prior positioning the absolute position can be compiled from received signals attributes and location of their transmitters.

Algorithms implemented for infrastructure-dependent positioning take advantage of WLAN signals, BLE beacons, UWB and RFID technologies.

WLAN

The number of public WLAN access points (i.e. hotspots) have increased around 200% each year from 2009 to 2011 as stated in *Wireless Broadband Alliance Industry Report* 2011. This increase expectancy continued throughout the following years till 2015 as illustrated in Fig. 2.2. According to Gabriel

(2014) between 2013 to 2015 more then seven million hotspots have been deployed annually with a steady increase. Number of hotspots is expected to increase 70% between 2015 and 2020 as stated in Howson (2015).

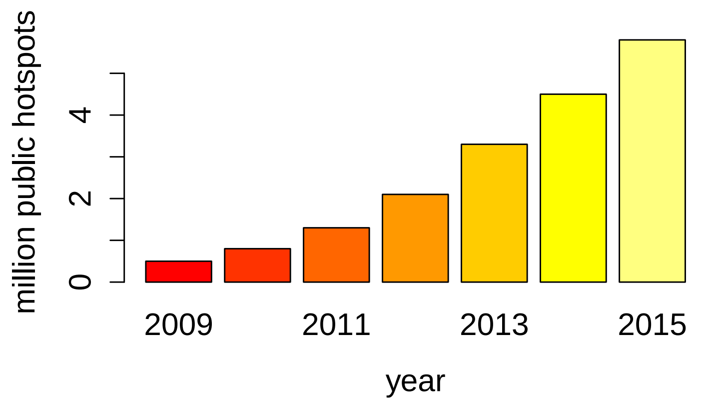

FIGURE 2.2: Number of public hotspots in the world compiled based on data extracted from *Wireless Broadband Alliance Industry Report* (2011).

Due to the increasing availability of WLAN signals, positioning systems leveraging the existing WLAN infrastructure of buildings for location estimation are cost efficient and thus preferable compared to other infrastructure-dependent positioning techniques. Indoor positioning based on WLAN signals can be established through trilateration or measurement of received signal strengths.

The multilateration technique utilizes the information on distance from reference points to calculate the position relative to these references. The absolute position is then compiled from the absolute position of the reference points and the relative position to them as illustrated in Fig. 2.3. Similar to GPS at least three reference signals are required to estimate the position in three dimensions or three reference signals to estimate the location in two dimensions.

Trilateration can be applied on WLAN signals through the TDOA or the TOA method as stated in Golden and Bateman (2007).

The TDOA method can be utilized in a similar fashion to the GPS so that a client can compute its location based on the signal received from multiple transmitters (i.e. WLAN access points). The challenge is however that unlike in GPS the client can listen to only one access point at a time as WLAN signals are transmitted in multiple channels as stated in e.g. *IEEE 802.11b Wireless LANs* (2007). Furthermore the access points are required to be synchronized. The distance is calculated through velocity of WLAN waves and the differences in time of arrival of WLAN packets where shorter time of arrival indicates a shorter distance.

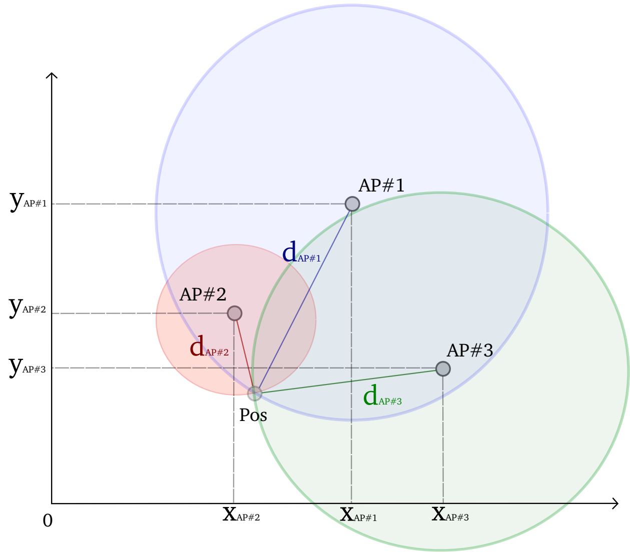

FIGURE 2.3: Trilateration in a coordinate system with x and y representing the position in 2-D. (AP - access point, d - distance, Pos - position).

The TOA method differs from TDOA as it can calculate the synchronization error between two nodes by measuring the propagation delay. The TOA works after the principle sending probe requests and measuring the time till the acknowledgment is received. Distance is measured by utilizing the information on the velocity of WLAN waves and the time of arrival difference of two packages.

The technique utilizing received signal strength is called Fingerprinting. As stated in Hansen et al. (2010) WLAN Fingerprinting works after the principle that RSSI values of WLAN signals read are compared with previously recorded WLAN signals and their signal strengths at mapped areas. The area with highest similarity of WLAN signals and signal strengths is then designated as the clients position as illustrated in Fig. 2.4.

It is important to note that although both techniques trilateration and WLAN Fingerprinting require dead-reckoning of WLAN signals prior location estimation the Fingerprinting technique does not require any knowledge on the exact position of WLAN access points to compute device's position, thus it is easier to apply than the trilateration technique.

As stated in Lang and Gu (2005) WLAN signals are effected by humidity, temperature, mobile objects in the environment (i.e. people), thus the algorithms need to employ tools to adapt their calculations respective environmental changes.

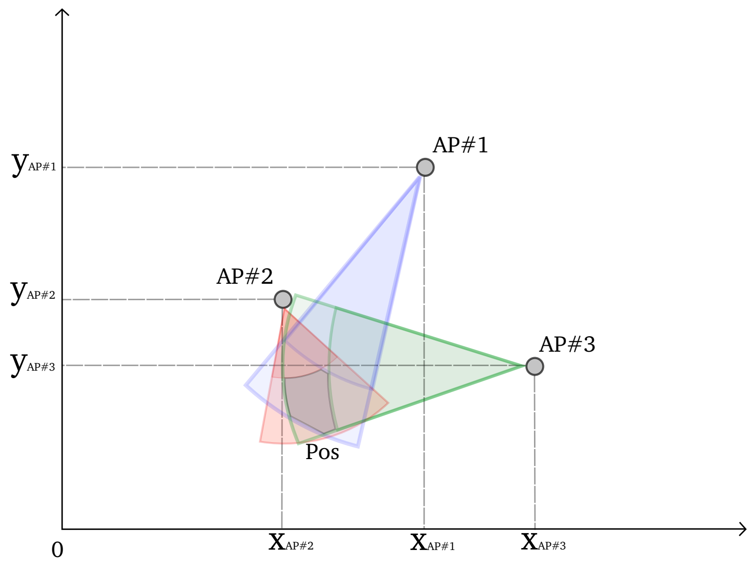

FIGURE 2.4: Fingerprinting in a coordinate system with x and y representing the position in 2-D. (AP - access point, d - distance, Pos - position).

BLE

As stated in Faragher and Harle (2014) both WLAN hotspots and BLE beacons work in 2.4 GHz frequency. There are however critical differences between WLAN and BLE technologies.

WLAN hotspots can transmit in one of the 14 channels as stated in Ferro and Potorti (2005) whereas BLE beacons transmit in one of the three channels. This difference makes BLE receivers to complete a scan faster then WLAN receivers, so that they can achieve a higher location update frequency.

According to Faragher and Harle (2014) the effect of obstacles -such as presence of a human body between transmitter and receiver- to BLE signals in ten centimeter range causes an error of one meter in calculated position.

The change in BLE signal strength even in close distances allows higher precision in computation of the position. As stated in Faragher and Harle (2014) a precision of up to three centimeter with 95% accuracy can be achieved by utilizing around 6-8 BLE beacons per fingerprint.

As BLE signals are in the same frequency with WLAN signals they are effected by environmental changes in similar fashion.

In Fig. 2.5 data on BLE signals RSS from Faragher and Harle (2014) and on WLAN signals RSS from *Wi-Fi Location-Based Services 4.1 Design Guide* (2008) by increased distance between receiver and transmitter is illustrated. The plot shows that the course of the RSS from BLE beacon is steeper then the RSS of the WLAN signal during the first ten meters. This indicates that BLE technology proves to be a better candidate for indoor positioning as it provides a higher precision in close range then the WLAN technology.

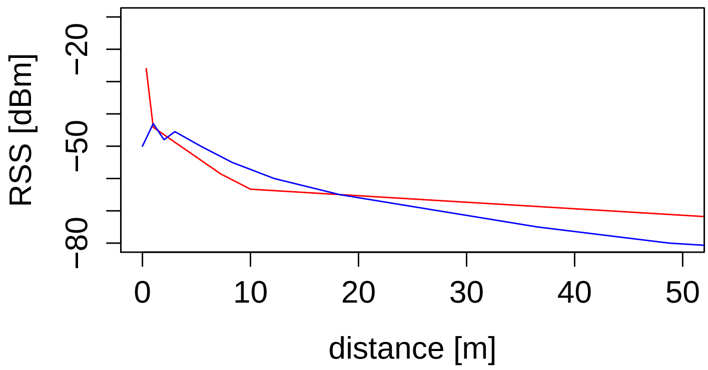

FIGURE 2.5: Comparison of RSS of a single BLE and WLAN signal by incrementing the distance of the receiver to the transmitter (red - BLE signal, blue - WLAN signal).

Furthermore the plot indicating BLE signal strength shows that change in BLE signal strength is more consistent compared to the change in WLAN signal strength when distance to the source is increased. During the first ten meters distance from the source the WLAN signal strength increases at two positions as shown in Fig. 2.5 unlike the BLE signal strength which constantly decreases when moved away from the signal source.

Due to the shorter range of BLE compared to WLAN signals as stated in Lee, Su, and Shen (2007) the utilized BLE signals are not as severely effected by environmental changes as the WLAN signals in terms of causing a positioning error.

UWB

The UWB-IR technology proposed in Krishnan et al. (2007) takes advantage of signals between 2.2 GHz - 6 GHz frequency range and utilizes the TAO method. The time information is coded by introducing a constant delay between two UWB pulses.

The constant signal stream from client is read by multiple receivers and the position is computed on the server.

As UWB signals are in a frequency range with a lower bound similar to the WLAN signals and higher bound at 6GHz they are effected by environmental changes in similar fashion or more severely then the WLAN signals.

RFID

The proposed technique in Ozdenizci et al. (2011) enables devices with NFC capability to compute their position by taking advantage of RFID tags deployed in the environment. The location update is required to be invoked manually through the operator.

While this technique is the most reliable procedure in terms of precision and processes position information faster then its alternatives utilizing the QR code, it lacks automation of position update.

2.1.3 Performance of IPSs

The aforementioned technologies utilized in IPSs which can provide an absolute position are inspected respective their deployment cost in terms of number of required devices as infrastructure and maintenance requirement at the highest precision & accuracy they can provide.

The maintenance requirement implies the necessity of signal maps' adaptation to environmental changes and is dependent on whether the technology utilizes signal strengths. Thus e.g. WLAN-TOA does not require maintenance of the initially created signal map.

As stated in Lee, Su, and Shen (2007) WLAN transmitters have a nominal range up to 100m while BLE and UWB transmitters are limited to a ten meter range.

The in Golden and Bateman (2007) proposed application of the TOA technique on WLAN signals claims to have a precision better then 5.5m in an environment where five WLAN signals are utilized to calculate the position. The WLAN Fingerprinting technique proposed in Hansen et al. (2010) claims to have a two meter precision when there are seven WLAN signals from access points utilized to calculate the position. As stated in Hansen et al. (2010) the WLAN-FP requires recalculation of fingerprints for adaptation to changes in the environment.

The in Krishnan et al. (2007) proposed method based on UWB is claimed to have a precision of 15cm when the client signal can be read by eight receivers.

According to Faragher and Harle (2014) the BLE technology can provide a precision of three centimeter with 95% accuracy provided there are around six or eight BLE signals utilized to calculate the position. As BLE beacons are battery powered they are required to be resupplied with battery.

The WLAN-FP and BLE technologies are designated as subject to maintenance due to aforementioned reasons. Although the technologies WLAN-TOA and UWB utilize signals in the same frequency range like WLAN-FP and BLE, there are no indications on maintenance requirement of these technologies in respective papers advertising techniques for indoor positioning.

The performance of each technology is shown in Table 2.1 respective the information retrieved from the proceedings referenced in this study. Amount of deployed devices providing best positioning results is given for most of the technologies as 8 devices.

TABLE 2.1: Comparison of technologies utilized in IPSs capable of providing the absolute position.

Technology	Deployment Cost	Maintenance Req.	Precision	Accuracy
WLAN-TOA	5	no	5.5 m	NA
WLAN-FP	7	yes	2 m	NA
BLE	8	yes	0.03 m	95%
UWB	8	no	0.15 m	NA
RFID	1	no	0.01m	100%

It is important to note that the comparison conducted in this table is based on the cited research papers in this study and thus it is subject to limitations such as effects of the hardware and influence of the test environment. Detailed and scientifically correct comparison can only be conducted when the proposed algorithms and technologies are tested in the same physical environment with priorly determined hardware specifications. Such a comparison has been made in Lymberopoulos et al. (2015) based on data generated during the Microsoft Indoor Localization Competition in 2014.

2.2 Location-based Services

In Schiller and Voisard (2004) Location-based Services are defined as integration of spatial information with conventional characteristics of services. The most critical attributes of these services are designated as personalization, universality and context-awareness.

In both Küpper (2007) and Lin and Nikita (2011) these services are divided into categories as 'Reactive' and 'Proactive' services. Within the framework of this study Location-based services are discussed according to the proposed business applications in Küpper (2007) due to the generic description of the Location-based services which can also be easily associated with respective definitions made in Schiller and Voisard (2004) and Lin and Nikita (2011). These business applications are associated in this study to one of the two categories respective their service type.

Each service is discussed in regard of its applicability as an Indoor Location-based Service at the university environment respective of its requirements such as accuracy, ubiquity and interoperability. In Table 2.2 Location-based Services listed in Küpper (2007) (left) are associated to services listed in Schiller and Voisard (2004) and their accuracy levels as requirement.

Although the association in Table 2.2 is about outdoor Location-based Services and does not reflect any numeric information regarding the precision and accuracy, it provides a comparative overview on the accuracy requirement of different services.

Furthermore the actors taking part at Location-based Services are examined as they are critical to create a system which is sustainable. To provide uniformity in the terminology, services described in this study are named identical to Küpper (2007).

TABLE 2.2: Association of Location-based services and their accuracy requirement.

Service	Associated Service	Accuracy
Inquiry and Information Systems	Point of Interest	Medium to High
Community	Child Tracking	Medium to High
Traffic Telemetrics	Personal Navigation	High
Fleet Management and Logistics	Fleet Management	Low
Mobile Marketing	Local Advertisement	Medium to High
Mobile Gaming	Gaming	Medium
Value Added	Location-Sensitive Billing	Medium to Low
Emergency	Emergency	High
Toll Systems	Electronic Toll Collection	Medium to High

2.2.1 Reactive

Reactive i.e. Pull services are described in Küpper (2007) as services which are user-activated only and provide information with context associated to user′s spatial data.

Reactive services are basically context aware responses to search inquiries. The location context can be provided by user manually or retrieved automatically through the device from which the inquiry is conducted.

Inquiry and Information Systems

The Inquiry and Information Systems implies the most basic version of Location-based Services where user invokes an information request and receives the requested information in context of user′s location.

This service can provide users at the university environment to inform them about their next to-go locations such as a seminar room or a meeting in that building. Users can also retrieve information on services provided by the building such as the opening hours of the library.

Community Services

Community Services implies the location inquiry on users invoked by another user. These services provide interaction between users based on their whereabouts.

The Community Service can allow users at the university to share their location with each other to make meetings on short notice easier by simplifying locating team members.

Traffic Telemetrics

The service Traffic Telemetrics provide users beside navigational assistance information on facilities close-by the target location.

This service can be utilized at the university environment by providing users with information such as where the nearest ATM or Coffee/Snack vending machine is. The service can also supply users with indoor navigation assistance.

Mobile Gaming

Mobile Gaming services allows users a level of augmented reality by enabling them to utilize their physical position as an input in a virtual game environment.

Mobile Gaming can be utilized at the university environment to familiarize freshmen with university infrastructure and to get to know each other. This service can also be utilized to create AI assisted guided tours for visitors.

Emergency

Emergency service informs the priorly set person or institution about the incident by providing them information on the invoking person and on the location of the incident.

This service can increase efficiency of medical and security personnel by enabling users to reach them not only faster but also by providing critical information simultaneously with both on-site and off-site (e.g. monitoring) team.

2.2.2 Proactive

Proactive i.e. Push services are described in Schiller and Voisard (2004) as services which imply that users receive messages based on their spatiotemporal activity.

Unlike Reactive services the Proactive services do require continuous tracking of user behavior. User's behavior is then analyzed in a certain frequency for a predetermined pattern or attribute value and the service provider reacts respective the outcome of this analysis.

Fleet Management and Logistics

Fleet Management and Logistics implies on the location information provided by devices upon position inquiry invoked by a user manually or in constant frequency by a tracking system.

Through the logistics service the departments of the university responsible for resupply tasks of automats can increase their efficiency by utilizing 'Internet of Things' technology.

Mobile Marketing

Mobile Marketing services send users information on products or services offered by the infrastructure the user is visiting at the moment or a close-by facility to the current position of the user.

This service can be utilized to inform users about ongoing events or new services at the building they are currently visiting. The service can personalize messages not only based on user profiles but also user behavior pattern so that e.g. a user spending most of the time in the library will be informed about new subscriptions and services the library offers. Furthermore information on users can be utilized to adjust digital billboards respective the common attributes of the user group standing close-by to the billboard. This allows personalization of advertisement in public spaces without jeopardizing single users privacy.

Toll Systems

Toll Systems provide automation of billing process which occur when a certain infrastructure is used.

The university can utilize this service by providing information on free capacity at various facilities such as free seats at libraries. The university can also take advantage of this service for checking attendance of students to classes.

Value added

Value added services provide price diversity for billing of services depending on the location the service is consumed from.

Value added services can be introduced by the university as a regulator for connection speed prioritizing transmissions of university students in comparison to transmissions made by third party users such as guest students or visitors. The regulation can be implemented also at faculty level so that students of a faculty will have prioritized transmissions when connected inside the infrastructure of their own faculty.

2.2.3 Actors

The Location-based Services are designated in Küpper (2007) as an institutional entity at which multiple actors take part in operational or nonoperational roles. Whereas operational roles do actively participate at Location-based Services as location- and content- provider or user, nonoperational roles have an influence on technological and regulatory level.

In Fig. 2.6 the operational and nonoperational actors of the proposed Location-based Service implementation in this study are illustrated in a similar fashion to Küpper (2007) and discussed in the context of the university environment.

Nonoperational roles consists of 'Finance', 'Research and development', 'Regulatory bodies' and 'Community'.

The actor 'Finance' represents commercial partners which have an interest in utilization of LBS or profit from it as a side effect. This role can be filled by the financial department of the university or a third party which has a financial relationship with the university e.g. companies supplying the university with Coffee/Snack vending machines or other products to be consumed by students visiting the university's premises.

'Research and Development' represents the actors who profit from LBS in terms of having a test ground for LBS architecture, performance evaluation of different algorithms and means for data collection on which business intelligence techniques can be applied. This allows to identify correlations between user profiles and user behavior to determine e.g. student performance and utilization of the library. The actors of 'Research and Development' may be stakeholders of a department of the university such as lecturers or employees conducting evaluations on utilization of university premises and services.

'Regulatory bodies' affect LBS to assure its compatibility with the jurisdiction which the university is subject to. This role can be filled by the university Information Technologies department which is also responsible to issue privacy policies and check the services conformity to them.

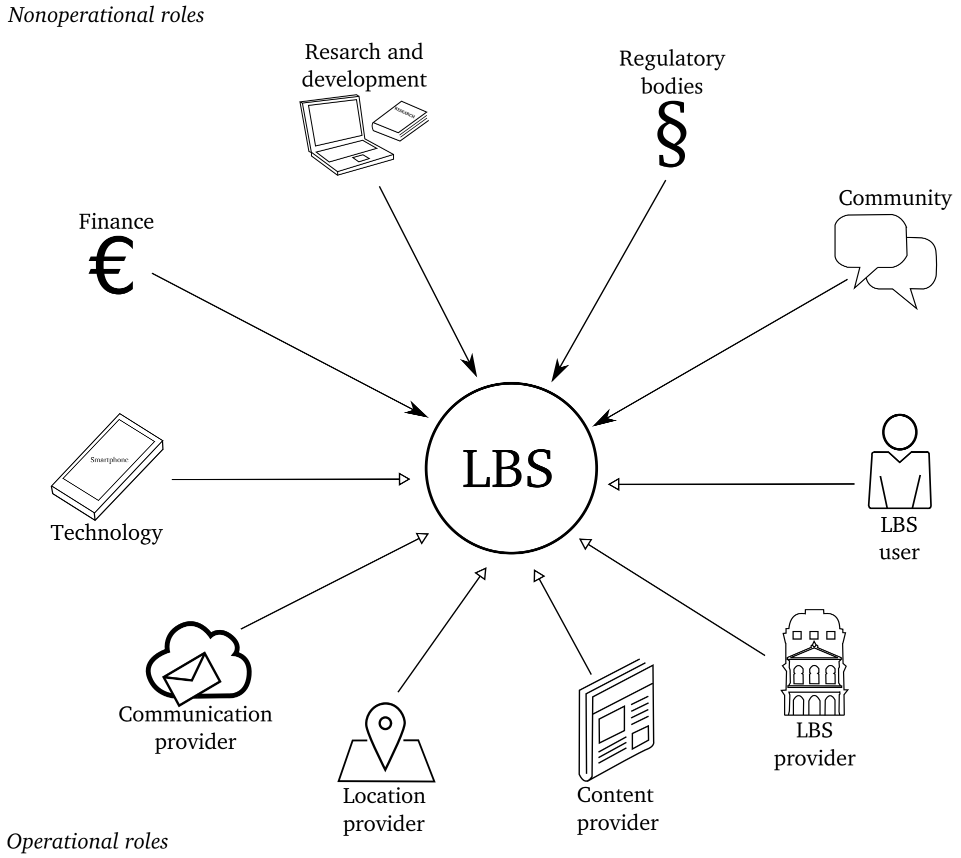

FIGURE 2.6: Actors of Location-based Services with operational roles designated by arrows ending with an empty triangle.

'Community' affects the usage of LBS based on its members perception of personalized services. Community members' perception of tools such as smart-phones enabling personalized online services influence the likelihood the LBS services to be employed on a daily basis by the community.

Operational roles consist of 'LBS user', 'LBS provider', 'Content provider', 'Location provider', 'Communications provider' and 'Technology'.

'LBS user' is the member of the aforementioned 'Community' which employs LBS. This role is filled by students, lecturers and visitors of the university.

The actor 'LBS provider' carries out the main responsibility for running and maintaining the LBS. This role can be filled by one of the university's governmental bodies such as the Faculty of Computer Science.

'Content provider' implies stakeholders of the LBS which are responsible for creating and updating content of services. The role 'Content provider' can be filled by lecturers and tutors of the university as well as the department of public relationship.

The actor 'Location provider' enables positioning data as context for 'Content provider's entries. This role can be filled by a commercial/non-profit institution offering an API for indoor positioning or by an university-internally developed system which provides the positioning feature.

The role 'Communication provider' implies operators responsible for the communication between 'LBS user' and 'Content provider'. This role is filled not only by e.g. network operators but also by companies providing technologies which are utilized to communication such as the Cloud Messaging service offered by Google Inc. as stated in *Cloud Messaging* (2016).

'Technology' represents the level of compatibility of delivered services to 'LBS user' devices. This role contains attributes on the operating system, software and protocols on which the LBS is transmitted.

3 WLAN Fingerprinting based on RSSI

The WLAN (i.e. WiFi) Fingerprinting is a technique utilizing dead-reckoning of WLAN signal strengths in areas from which the so called signal map is generated. Positioning is then conducted based on the comparison of measured signal strengths in the environment with those from the previously created signal map. The current location is determined as the area on the signal map which has the highest similarity of signal strengths to the measured signals.

As stated in Costilla-Reyes and Namuduri (2014) there are two phases of WLAN Fingerprinting;

1. Offline Phase (i.e. Calibration Phase)

   In the Offline Phase dead-reckoning is conducted in the areas which are to be included in the signal map. A signal map M may consist of one or more Fingerprints.

   $$M = \{f_1, ..., f_\mathrm{n}\} \tag{3.1}$$

   Each Fingerprint F embodies a location L, measured signals S (i.e. MAC Address of the access point from which the signal originates) and their signal strengths R.

   $$F = \{L, S = \{s_1, .., s_\mathrm{n}\}, R\} \tag{3.2}$$

   Costilla-Reyes and Namuduri (2014) proposes three approaches for selecting signals to be discarded during compilation of a Fingerprint; "InfoGain, RandMean, MaxMean". The InfoGain procedure is about determining the most influential signals for positioning by using descriptive statistics. The RadMean procedure conducts the signal selection randomly and the MaxMean procedure allows only signals to be selected whose signal strengths are above a manually determined threshold.

   The approach for selecting irrelevant signals is made respective the occurrence frequency of these signals in scan results conducted at the same location.

   As signal measurement results vary for the same location in each scan instance multiple measurements are required to prevent calibration errors.

   Unlike the signal strength representation in Costilla-Reyes and Namuduri (2014) and Hansen et al. (2010) with a single value, signal strengths in Fingerprints of the proposed algorithm in this study consists of two values standing for the minimum and maximum signal strengths.

$$R = \{(r_{\mathrm{min}_1}, r_{\mathrm{max}_1}), .., (r_{\mathrm{min}_\mathrm{n}}, r_{\mathrm{max}_\mathrm{n}})\} \tag{3.3}$$

Location L is composed of location's 3-D coordinates and its geographical position G.

$$L = \{x, y, z, G\} \tag{3.4}$$

The x, y denotes location's coordinates on the floor map of the building while z represents the floor on which the location stands. The geographical position is given in Fingerprints of this study as building address. Although the geographical position is admittedly irrelevant for indoor positioning it is utilized in this study as an indicator for the correct association of floor maps.

2. Online Phase (i.e. Positioning Phase)

   The Online Phase is the stage where indoor positioning is carried out. In this phase a signal measurement is conducted. Through comparison of signals and their strengths with Fingerprints the position is estimated.

   The reason why this phase is called "online" is mainly because of the requirement for distribution of Fingerprints from a central source. Depending on the architecture of the positioning system the positioning of a client can be conducted on the server as proposed in Bolliger (2008) or on the client devices as proposed in Costilla-Reyes and Namuduri (2014).

3.1 Related Work

The algorithm proposed in this study is inspired by Hansen et al. (2010) which addresses the challenge in utilization of unreliable WLAN signals with an algorithm capable of dynamically adjusting itself to environmental changes and providing a robust positioning performance.

The algorithm introduced in Hansen et al. (2010) relies on user contribution conducted manually to adjust existing Fingerprints and to add Fingerprints for new locations to the database. To prevent wrongful Fingerprint entry by users the algorithm enforces a two meter distance between Fingerprints. As optimal range between two WLAN Fingerprints the distance of three meter is suggested in Elnahrawy, Li, and Martin (2004).

King, Haenselmann, and Effelsberg (2007) suggest the minimum number of scans for a Fingerprint to be 20. The algorithm proposed in Hansen et al. (2010) does not enforce any scan amount threshold due to its design.

The Fingerprints consist of a single value defining the signal strengths so that evaluation is conducted through computation of Euclidean distance between calculated and actual positions.

The proposed algorithm has two modes; Integral Tree and Cluster. The Integral Tree utilizes Fingerprints with time stamps for adjusting itself to environmental changes. The Cluster disregards time stamps and utilizes multiple Fingerprints to compile a single Fingerprint for each location. Furthermore two other methods have been evaluated in Hansen et al. (2010); base-single and base-collect. The base-single method is described as creation of a Fingerprint for a location from one scan result, whereas the base-collect methods compiles the Fingerprint from multiple scan results.

3.2 The Algorithm

The self-adapting dynamic indoor positioning algorithm proposed in this study is an approach for the Calibration Phase of WLAN Fingerprinting which automatizes the maintenance of Fingerprints and enables the adaptation of Fingerprints to environmental changes continuously during its runtime.

The algorithm proposed in this study differs from the proposed algorithm in Hansen et al. (2010) in 4 aspects:

- The user contribution is not manually invoked. Instead it is collected automatically. The mobile application determines through accelerometer sensor whether the user is in move so that no textual warning is required informing the user to stand still. The user contribution is limited to areas with an existing Fingerprint. New Fingerprints are created in a similar fashion to user contribution, but this time the contribution is required to be invoked manually. For creating new Fingerprints a separate mobile application is present which is available only to personnel responsible for the Administration of the system.
- The proposed algorithm in this study allows for the minimum scan amount, required for the creation of Fingerprints, to be enforced.
- The Fingerprints in this study do not have a time stamp. They include however two values to define minimum and maximum signal strengths received from an access point.
- The proposed algorithm is a variation of the base-collect method. An artificial imprecision is introduced to signal strengths during the last phase of the algorithm described in the sub process "Adjust through Simulation".

The algorithm proposed in this study utilizes "Scan Amount", "Simulation Range", "Occurrence Threshold" and "Time Interval" information for regenerating and adjusting Fingerprints.

Furthermore through decreasing the "Time Interval" and increasing the "Scan Amount" it is possible to change the dynamics of the algorithm so that it works in an "adjust only" mode, where the Fingerprints return to their original state at the end of the day. The changes imposed during the day through e.g. human presence are in this case volatile. This mode does not allow for compilation of new Fingerprints.

The proposed algorithm illustrated as a process in Fig. 3.1 starts with retrieval of the aforementioned operation critical values. Signals (here i.e. scans as each scan contains signals marked with same time stamp) recorded between current time and the given "Time Interval" value subtracted from current time are copied into a temporary table in a database. Only these signals are considered relevant for further steps of the algorithm. The relevant signals are processed ordered by the building code they belong to.

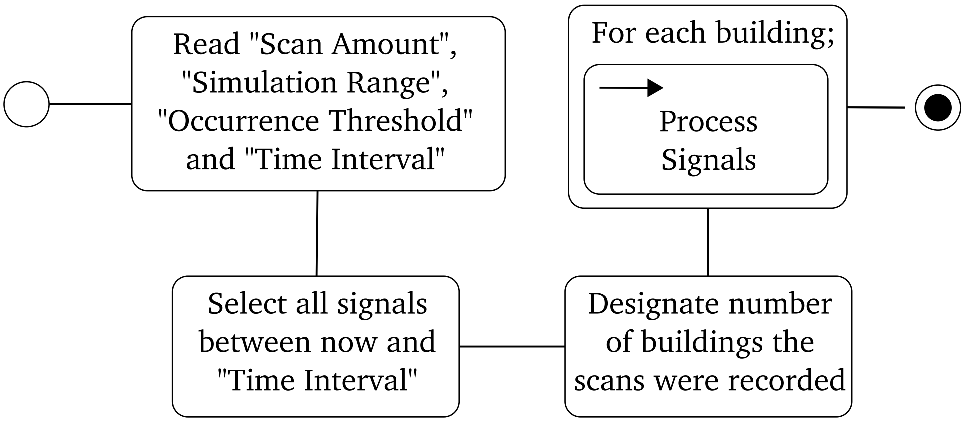

FIGURE 3.1: WLAN Fingerprinting Algorithm as a Process.

The signals of each building are processed respective to the location at which they were recorded. The sub process ends with generation of Fingerprints as illustrated in Fig. 3.2.

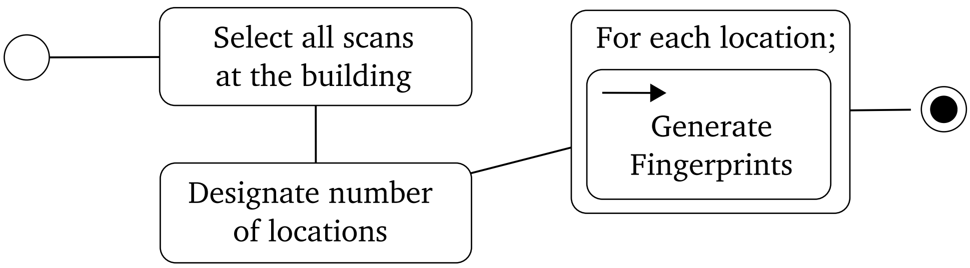

FIGURE 3.2: Sub Process: "Process Signals".

The Fingerprint generation for a location as illustrated in Fig. 3.3 starts with a data cleaning operation which eliminates signals occurring in too few scan results recorded at that location. If there are enough scans conducted at the location a new Fingerprint is generated and adjusted. However if there are not enough scans belonging to that location the existence of the Fingerprint for that location is inquired. If there is a Fingerprint present it is treated the same as a new Fingerprint and adjusted. In the absence of an existing Fingerprint and too few scans conducted at that location no further step is undertaken and the process ends.

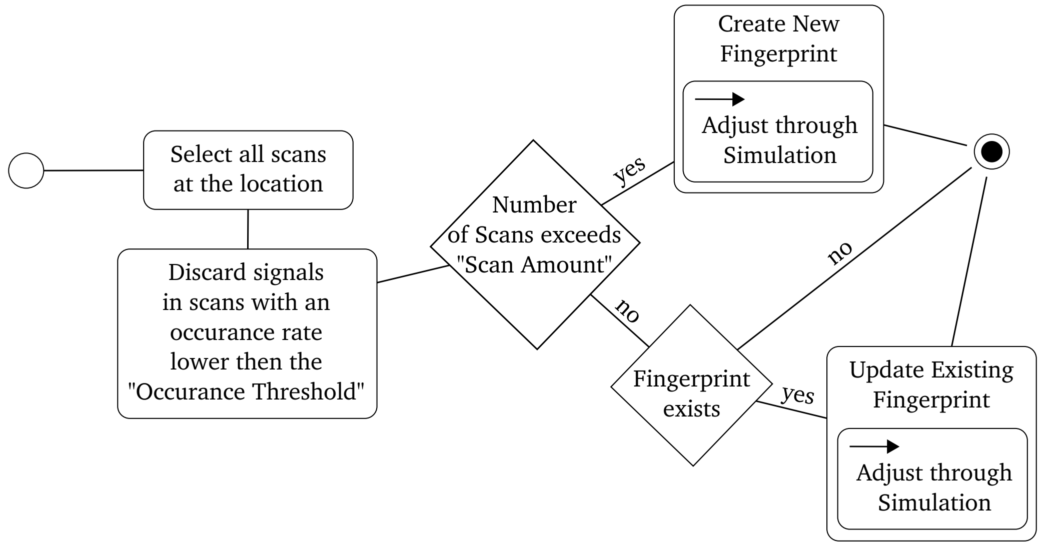

FIGURE 3.3: Sub Process: "Generate Fingerprints".

The sub process "Adjust through Simulation" illustrated in Fig. 3.4 embodies the operations which introduce a level of imprecision to the recorded signal strengths. The "Simulation Range" decides the number of variance combinations to be tested during simulation for all existing Fingerprints. Each signal recorded through multiple scans includes a maximum and a minimum signal strength value.

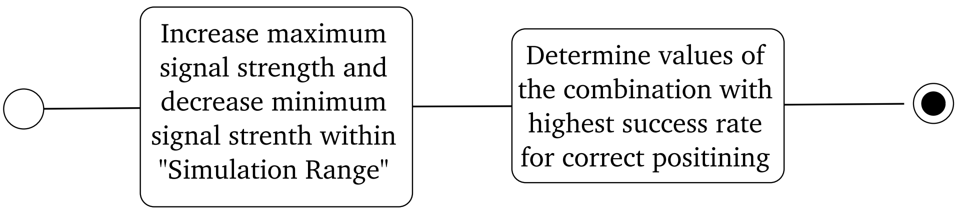

FIGURE 3.4: Sub Process: "Adjust through Simulation".

These values are then artificially altered during the simulation to study the effects of enforced signal strength imprecision on accurate positioning. When a value combination for imprecision is detected which delivers a higher success rate, these values will be added/subtracted from measured maximum and minimum values and recorded as a part of the Fingerprint.

In Fig. 3.5 an arbitrary Fingerprint is illustrated which consists of three signals originating from access point 1, 2 and 3. The Grey colored sector stands for the measured signal strength range consisting of a minimum and a maximum signal strength, while m stands for median of measured signal strengths. The marking c represents measured signal strengths during a positioning instance by a client device. As only the $c_{AP\#1}$ lies in the Grey sector this Fingerprint will get only one point. If there are no other Fingerprints with a higher point (i.e. hit amount) the current Fingerprint's location will be determined as users position, else the Fingerprint with the highest hit amount will be selected. As the sub process "Adjust through

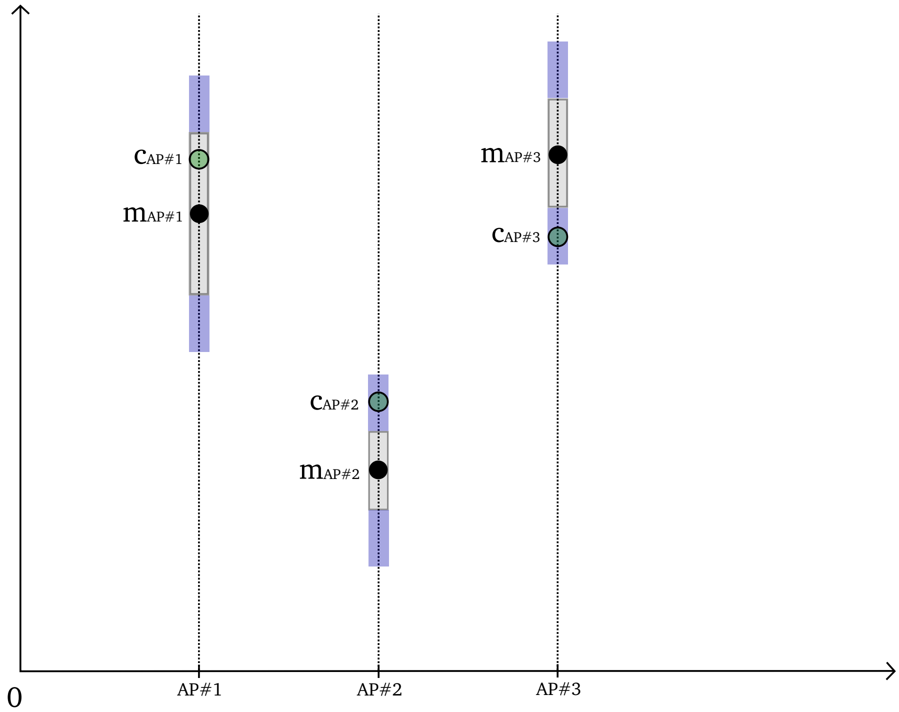

FIGURE 3.5: Visualization of a Fingerprint's structure at an arbitrary location with x-axis representing access points, y-axis representing the signal strength.

Simulation" introduces an artificial imprecision illustrated in Blue color, the same Fingerprint has now three measurement points marked with c in the signal strength range of its access points, thus it has now a hit amount of three.

In the Positioning Phase the client conducts WLAN signal strength measurements and compares the result with access point MAC addresses and the associated maximum and minimum signal strengths from the respective Fingerprint of each location in the signal map. Each location is evaluated in a way that it receives one point for each signal measured within the maximum minimum signal range from the Fingerprint of that location. Once all locations are evaluated the location with the highest points is designated as current location of the client.

It is important to note that algorithms e.g. proposed in Dornbusch and Zündt (2005) employing Fingerprints, where each signal strength is represented with a single value, utilize Euclidean distance for computation of the level of similarities of Fingerprints with the signal scan conducted during positioning phase. The Fingerprint structure utilized by these algorithms proves to be not an optimal candidate for the adjustment conducted by the algorithm of this study.

3.3 The Simulation

The main objective of the simulation program is to designate best dBm values for the introduced imprecision within the sub process "Adjust through Simulation".

Once the program is executed it calculates the optimal solution by testing all possible combinations for the given "Simulation Range". In Fig. 3.6 is an example output retrieved during one of these calculations. At the end of each run-time it prints the achieved success rate in %.

```
Starting Simulation.. [Range: 5]
Calculating variance for WHR19_ErdgeschossVorEingang. Testing min_var=0, max_var=1 Success rate: 0.9[success=9.0, total=10.0]
Calculating variance for WHR19_ErdgeschossVorEingang. Testing min_var=0, max_var=2 Success rate: 0.9[success=9.0, total=10.0]
Calculating variance for WHR19_ErdgeschossVorEingang. Testing min_var=0, max_var=3 Success rate: 0.9[success=9.0, total=10.0]
Calculating variance for WHR19_ErdgeschossVorEingang. Testing min_var=0, max_var=4 Success rate: 0.9[success=9.0, total=10.0]
Calculating variance for WHR19_ErdgeschossVorEingang. Testing min_var=0, max_var=5 Success rate: 0.9[success=9.0, total=10.0]
Calculating variance for WHR19_ErdgeschossVorEingang. Testing min_var=1, max_var=0 Success rate: 0.9[success=9.0, total=10.0]
Calculating variance for WHR19_ErdgeschossVorEingang. Testing min_var=1, max_var=1
```

FIGURE 3.6: Screenshot of the terminal output during runtime.

The simulation program in this study is also applied with different settings to determine best values for "Occurrence Threshold" and "Simulation Range", which are to be provided manually by the Administrator before the program is executed.

The Fingerprint adaptation code is implemented by using a static and a dynamic variance for appliance of further imprecision. Unlike the dynamic variance the static variance method applies one value to be added to maximum signal level and subtracted from minimum signal level for all Fingerprints belonging to the same building. This is also the reason for introduction of a building prefix in names of Fingerprints which is obsolete when dynamic variance method is utilized for Fingerprint regeneration and adjustment. The aim in utilizing static variance is to determine the imprecision range (i.e. "Simulation Range") with the highest success rate which is to be used in the dynamic variance method.

Figure 3.7 shows the graph of success rate for the appliance of a static variance. The maximum success rate of 63% has been reached at a variance value of three, while the initial rate for variance value 0 is 58%.

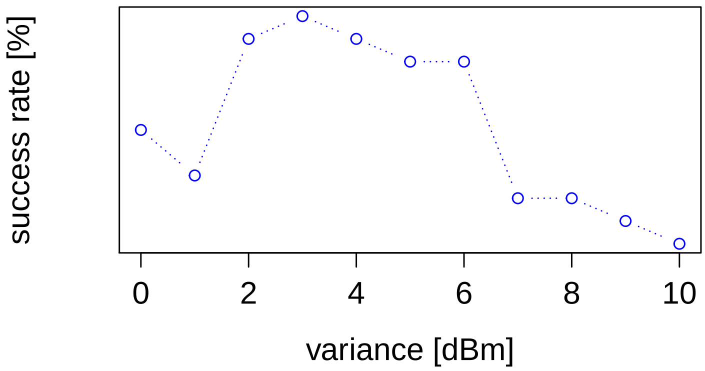

FIGURE 3.7: Artificial fingerprint imprecision with a static variance and maximum success rate as 63%.

The calculation for ten variances has taken 64712 ms (~1 min) on a 2.4 GHz processor for 26 locations and ten scan results for each location.

As shown on Figure 3.7 the success rate stays constant between five and six and drops steeply after a variance of six. Thus the value five is determined as the optimal value for "Simulation Range".

Figure 3.8 shows the graph for appliance of Fingerprint imprecision with a dynamic variance and different occurrence thresholds for a set of measurements with mobile access points present in the environment having a negative impact on the integrity of collected data.

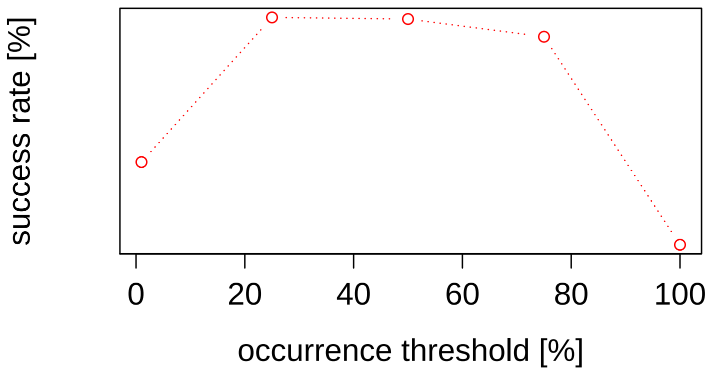

FIGURE 3.8: Artificial Fingerprint imprecision with a dynamic variance and maximum success rate as 95% for different occurrence thresholds.

The success has increased from initial 61% for an occurrence threshold of 1% to 95% for an occurrence threshold of 25%. Thus the value 25% is determined as optimal for "Occurrence Threshold". The graph in Fig. 3.8 illustrates the potential negative impact of mobile access points on the success rate. It also shows that the dynamic variance method has a similar performance to the static variance method.

The calculation for five variances has taken 624088 ms (~10 minutes) on a 2.4 GHz processor for 26 locations and ten scans for each location.

Although the dynamic variable increases the positioning accuracy for 32% it does require approximately ten times longer run-time duration than the static variable.

3.4 Limitations

As the technology utilized for indoor positioning is WLAN (i.e. WiFi) Fingerprinting it is by nature subject to all limitations which apply for positioning conducted with WLAN signals. The algorithm introduced in this study is able to overcome these general limitations. It does however have its own shortcomings.

The proposed algorithm contains mainly two limitations, i.e. on the adaption to environmental changes and on outlier detection.

As the algorithm utilizes users' devices to collect sample scan results, it requires a minimum amount of sample scan results sent from each mapped location independently from whether the samples are sent by a single user or multiple users. The minimum amount mentioned here refers to the value of the "Scan Amount" variable.

The algorithms' limitation on outlier detection is its lack of capability to detect anomalies in the signal strengths. The application is able to detect anomalies by classifying signals as valid or invalid based on the frequency of their occurrence in measurements conducted at the same location. However it has no tools to expose Fingerprints originating from the same location which have different signal strength values.

Tests conducted during this study revealed that signal measurements conducted with tablet devices i.e. *E8712* (2013) and smart-phone devices i.e. *E9384* (2014) differentiate in measured signal strengths for the same location. The algorithm does not have any means to either differentiate Fingerprints for devices of both type or to generate two types of Fingerprints each suitable for a specific type of device.

All measurements in this study for creating the Fingerprints and evaluating their accuracy have been made with a smart-phone device i.e. *E9384* (2014).

4 Design of Indoor Location-based Services

This chapter examines location-based services in terms of their suitability to be utilized at the university environment. It also discusses the perception of the services by users.

Junglas and Watson (2008) conducted a survey about the perception of users on usefulness and ease-of-use of LBS as a part of their research, where users were given three tasks. The first task was a location tracking task such as finding a person. The second task was about a location-aware task such as finding the closest infrastructure providing a specific service. The third task involved an information inquiry without a location component.

The radar plot in Fig. 4.1 derived from the data of that survey illustrates changes in user's perception when equipped with a LBS to complete the given task. The positive change in perception is highest when tracking mobile objects such as other users. The positive change (i.e. Δ) in perception on location-aware tasks is similar to location tracking. The perception change on LBS is negative for tasks which do not have a location component.

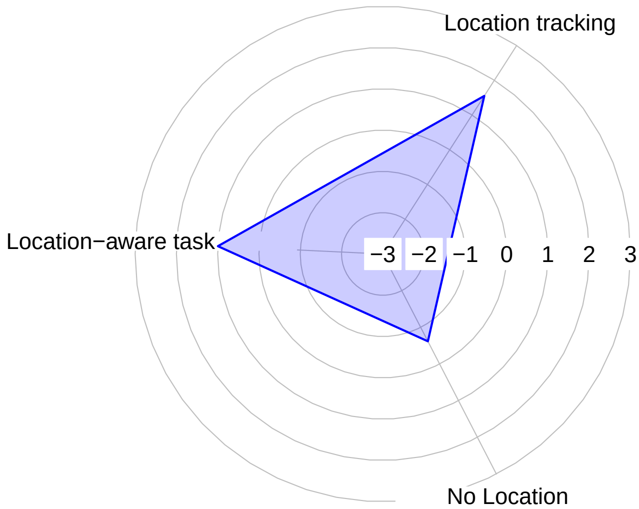

FIGURE 4.1: Δ Perception of users on usefulness and ease-of-use of LBS for 3 different tasks (Evaluation schema; -3: strongly disagree, 3: strongly agree).

Based on Junglas and Watson (2008) the service "Inquiry and Information Systems" has been designated as not critical for implementation as the change of users' perception on this service is negative thus making the utilization of LBS superfluous. Services such as "Mobile Gaming", "Emergency", "Value Added" and "Fleet Management and Logistics" require by their nature a high level cooperation of the "LBS Provider" (here: governing bodies of respective departments at the University of Vienna) for implementation. As such a cooperation was neither existing nor asked for during the completion of this study these services have also been designated as not critical for implementation.

4.1 Features for LBS User

"Community Service" and "Traffic Telemetrics" are the features for LBS User considered as feasible for implementation based on the Fig. 4.1. Both features are adapted to the university environment while keeping in mind that they will be utilized by students, lecturers and visitors of the university.

4.1.1 Community Services

The Community Service feature allows users to share their indoor position with other users. Only users, that are friends with each other in the database, can use this service as the location sharing can only be conducted in case a user sends a friendship request to another user and the recipient user approves this request. It is further required that the user sending a friendship request knows the user account name of the recipient user as there is no possibility for users to view the list of registered users in the database. All users willing to benefit from this service are required to register to become eligible for sending and receiving friendship requests. The registration can only be conducted on a user's Android device and consists of pairing a user's device with the user's account credentials which are provided to all users affiliated with the university by the universities computer center.

4.1.2 Traffic Telemetrics

The Traffic Telemetrics feature decided for implementation has additional limitations to this services original description as the implementation in this study lacks any navigational assistance and location-aware inquiry. The implementation of Traffic Telemetrics consists only of a visual representation of the floor map the user is located on. This way the feature provides additional information with a location context to the user.

4.2 Features for Research and Development

The service "Toll Systems" is viewed as feasible for Research and Development and will be implemented as a part of this study. The feature is adapted to the university environment with respective constraints on the inquiry of users' position information to provide a privacy friendly system.

4.2.1 Toll Systems

The Toll Systems service consists of two parts,i.e. location tracking of users and analytics.

The location tracking is combined with the location history feature to be used as an automated attendance tracker. This feature, which provides real time position of students, allows lecturers to check the attendance on-site and add students who e.g. do not have enough battery to use their smart phone manually to the attendance list. The location history feature allows lecturers to check attendance of students during the semester.

The analytics feature takes advantage of the location history of users to visualize area utilization in terms of population and duration. It also creates heat maps to portray comparative utilization of areas by users and to depict user groups with similar spatio-temporal behavior.

4.3 Features for Content Provider

Content Providers are enabled with the "Mobile Marketing" service which is a location-aware messaging feature. This feature can be operated by lecturers or student assistants to forward critical information such as exam locations and information on short notice such as room changes to students with a location context.

4.3.1 Mobile Marketing

The Mobile Marketing feature, which is primarily a tool for instantaneous notification of LBS users, can be operated also by a machine (i.e. software) besides university employees. The notification feature creates messages which are delivered to its recipients only when they are located at a predetermined position in the building in the predetermined time interval. The feature, when operated by a machine, can be utilized to send automatized notifications e.g. informing visitors on closing time of the library and urging them to leave.

5 Implementation of the Server-side Application

This chapter presents the architecture of the system implemented in this study. It also embodies web services and the database design which constructs the backbone of the indoor location-based services.

The objectives of this study are: (1) to create a design which supports the implementation of the indoor location-aware services and (2) to provide a generic environment allowing components of the system to have minimal coupling and thus to be able to function as a distributed system.

5.1 Architecture

The proposed system as illustrated in Fig. 5.10 consists of seven components. Each component except "Rserve" communicates directly with the Database component.

The component "Rclient" is executed on system boot and runs in a loop in the background. Unlike other components "Rclient" does not allow users to make changes in its behavior during run-time such as e.g. changing its loop frequency which by default is set to five minutes.

At each loop "Rclient" reads information on all users and how much time they spent at all locations from the "EndUserLog" table of the database through JDBC. The query "UserLocationData" read by "Rclient" looks e.g. as shown in Fig. 5.1. "Rclient" calculates how many location updates have been made by each user at each location and writes the results into a CSV file.

end_user_log_id	end_user_log_location	end_user_log_date	end_user_log_regid	end_user_id
348364	WHR29_1stFloorBeforeLift	2016-02-01 20:45:52	[redacted]	208
348365	WHR29_1stFloorBeforeSR7	2016-02-01 20:45:37	[redacted]	208
348366	WHR29_1stFloorBeforeSR7	2016-02-01 20:45:22	[redacted]	208
348367	WHR29_1stFloorBeforePC3PC4	2016-02-01 20:45:07	[redacted]	208
348368	WHR29_1stFloorBeforeLift	2016-02-01 20:44:52	[redacted]	208
348369	WHR29_1stFloorBeforeSR6	2016-02-01 20:44:37	[redacted]	208
348370	WHR29_3rdFloorBeforeLift	2016-02-01 20:44:22	[redacted]	208
348371	WHR29_1stFloorBeforeLift	2016-02-01 20:44:07	[redacted]	208
348372	WHR29_1stBasementBeforeSR1SR2SR3	2016-02-01 20:43:52	[redacted]	208
348373	WHR29_1stFloorBeforeSR8	2016-02-01 20:43:37	[redacted]	208

10 rows in set (0.00 sec)

FIGURE 5.1: Screenshot of "UserLocationData" read from database by "Rclient".

The generated CSV data from the query result looks like as shown in Fig. 5.2 and is saved in a respective file, which is located in a File System in which the CSV file is locally accessible to "Rserve". Thus the CSV file is required to be on the same machine as "Rserve" is running on. This location is set as `/home/administrator` in the implementation within this study.

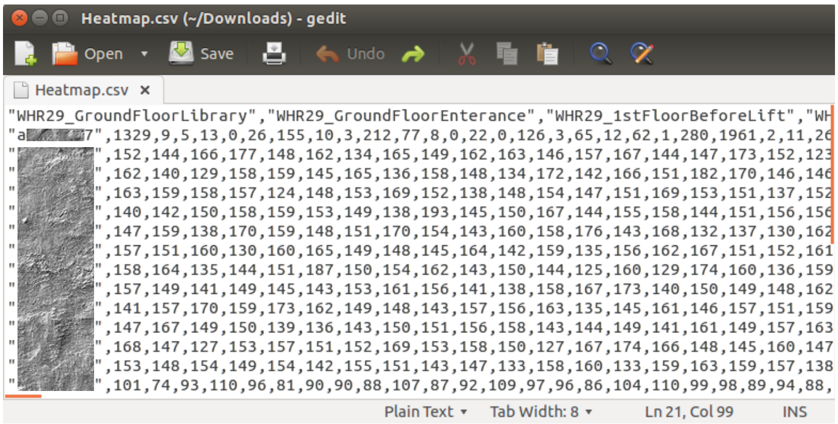

FIGURE 5.2: Screenshot of "UserLocationData" read from the database, interpreted and converted into a CSV file.

Once the respective CSV file(s) are generated "Rclient" communicates with "Rserve" over a Telnet connection prompting it to execute "Rscript" commands shown in Listing 5.1 for creating the visual representation of the data in the CSV files.

```
mydata <- read.table("/home/administrator/Heatmap.csv", header=TRUE, sep=",")
mtscaled <- as.matrix(scale(mydata))
try(jpeg("test.jpg",width=1200,height=1200))
mtscaled = mtscaled[rowSums(!is.na(mtscaled))!=0, colSums(!is.na(mtscaled))!=0]
heatmap(mtscaled, Colv=F, scale='none', margins = c(20, 20))
dev.off()
```

LISTING 5.1: Rscript sent from Rclient to Rserve over Telnet connection

After "Rserve" receives the commands it loads the content of the CSV files into its memory and generates the respective image data and sends them to "Rclient" over the Telnet connection.

The final task of "Rclient" is to generate the image from the respective image data and save it into the predetermined system folder, which is the folder where the website is located on the server. This folder is located on this implementations server in `/var/www/html`.

The component "GcmMessenger" program is executed on system boot and runs in a loop. Its behavior can be manipulated during its run-time through the "AdministrationPanel" component by changing respective values in the Database.

The frequency of the "GcmMessenger" component is specified in the database, e.g. 2000 milliseconds. At the end of each loop it creates a new Thread to review and edits the content of Message and Association tables in the database as shown in Figure 5.3.

```java
public class GcmMessenger {
    public static void main(String []args) throws InterruptedException, SQLException {
}

class Sender extends Thread {
    String url = Utils.getDatabaseCredentials().get("url");
    String user = Utils.getDatabaseCredentials().get("user");
    String password = Utils.getDatabaseCredentials().get("password");

    public Sender(String str) {

    public void run() {

    private void clean() {

    private String getDate() {

    private String getServerKey() {

    private void sendMsg(String message_id, String message_location, 

    private void changeAssociationStatus(String association_id, String message_id) {

    private void checkAssociations(String message_id) {

    private void changeMessageStatus(String message_id) {

    private void sendGet(String message_content, String server_key, List<String> regids) throws Exception {
}
```

FIGURE 5.3: Screenshot of "GcmMessenger" program's code creating a new Thread at each loop.

When a new Message for delivery is detected, which has in the field `message_status_all` the value `pending` as shown in Fig. 5.4, the "GcmMessenger" forwards the message to its recipient (i.e. Client component) listed in Association table through Google Cloud Messaging Connection Server. It edits the Messaging Data in the Database component with an indicator that it has been processed, i.e. by changing the `message_status_all` field in Messages table to `sent`. To assure that sent messages reach recipients with a delay no longer then three seconds once the message has been forwarded "GcmMessenger" is set to forward at maximum 700 messages at once. Remaining Messages are sent during the next loop.

```
+---------------------+---------------------+---------------------------+------------+----------+---------------------+--------------------+
| message_end_time    | message_start_time  | message_location          | message_id | admin_id | message_content     | message_status_all |
+---------------------+---------------------+---------------------------+------------+----------+---------------------+--------------------+
| 2016-04-19 19:00:09 | 2016-04-05 14:21:03 | ALL                       |         53 |        5 | System Test Message | sent               |
| 2016-04-07 14:45:00 | 2016-04-07 14:20:00 | ALL                       |         54 |        5 | System Test Message | outdated           |
| 2016-04-07 14:50:00 | 2016-04-07 14:45:00 | WHR29_GroundFloorLibrary  |         55 |        5 | System Test Message | cancelled          |
+---------------------+---------------------+---------------------------+------------+----------+---------------------+--------------------+
3 rows in set (0.00 sec)

+----------------+----------------+------------+-------------+
| association_id | message_status | message_id | end_user_id |
+----------------+----------------+------------+-------------+
|            280 | sent           |         53 |         184 |
|            281 | pending        |         54 |         184 |
|            282 | cancelled      |         55 |         184 |
+----------------+----------------+------------+-------------+
3 rows in set (0.00 sec)
```

FIGURE 5.4: Screenshot of a query from Message and Association tables showing every possible value for the fields `message_status` and `message_status_all`.

The value `pending` means that the message was not delivered due to the tracked user not being located at the target area in the given time interval associated to that message. The value `outdated` means that the message was not sent to all recipients and the end value of the time interval has passed the current time, thus "GcmMessenger" will no longer try to send this message to the remaining recipients. The value `canceled` means that the sending process has been manually terminated (i.e. canceled) and will not proceed anymore in the future.

To enable transparency administrators are revoked from deleting messages. Each message is associated to an administrator and can be seen by all administrators. Through the traceability feature of messages an environment is created where administrators can police each other. The aim is to deter administrators from misusing the system by sending users spam messages.

The "AdministrationPanel" component utilizes the website where statistical data on users can be visualized and features to manage the indoor positioning system can be accessed. It furthermore applies visual elements (i.e. Heatmaps) provided by the "Rclient" component as image files and generates charts by reading location data of users and utilizing Google Charts service. It can also edit the Fingerprinting Data and provide an interface for the Client component to download floor maps of buildings for which Fingerprints have been created as images. More information on this component can be retrieved from Chapter 6.

The "FingerprintGenerator" component utilizes the Fingerprinting Data on the Database and generates Fingerprints which it provides through HTTP interface to the Client component. Note that the "FingerprintGenerator" component mentioned here refers to the simulation program introduced in Chapter 3 and implemented as `WifiFingerprintGenerator.jar` while the Fingerprinting Data implies the values the simulation program requires during its run-time and the information regarding association of floor map images to Fingerprints as shown in Fig. 5.5. Fingerprints not associated to any floor map in the Image table are automatically associated to a dummy floor map image named `someFloorMap.png` and the location is marked at the position P(0|0) pixels on this image file.

```
+----------+-----------------------------------+-----------------------------------+--------------+--------------+
| image_id | fingerprint_name                  | file_name                         | x_coordinate | y_coordinate |
+----------+-----------------------------------+-----------------------------------+--------------+--------------+
|       33 | WHR29_GroundFloorBeforeEnterance  | WaehringerStr.29,1090Vienna_0.png |           33 |          294 |
|       34 | WHR29_GroundFloorEnterance        | WaehringerStr.29,1090Vienna_0.png |          140 |          290 |
|       35 | WHR29_GroundFloorBeforeLift       | WaehringerStr.29,1090Vienna_0.png |          236 |          211 |
|       36 | WHR29_GroundFloorBeforeGarden     | WaehringerStr.29,1090Vienna_0.png |          318 |          365 |
|       37 | WHR29_GroundFloorLibrary          | WaehringerStr.29,1090Vienna_0.png |          384 |          232 |
+----------+-----------------------------------+-----------------------------------+--------------+--------------+
5 rows in set (0.00 sec)
```

FIGURE 5.5: Screenshot of a query showing association of image files and Fingerprints.

The code snippet in Fig. 5.6 reveals the main steps and the execution order of the implementation according to the algorithm proposed in this study. Note that the methods in lines 57 and 65 are replaced with the code from lines 56 and 64 in the original program as these lines in the given code snippet refer to methods written for testing with static data (i.e. signals).

```java
        try{
            long startTime = System.currentTimeMillis();
            Connection con = DriverManager.getConnection(url, user, password);
            // STEP 0: Empty sc_mac_address, scan.
            ScanDAO.empty(con);

            // STEP 1: Translate from ScanRepository into scan, sc_mac_address.
            // Argument: time_interval
            int time_interval = getTimeInterval(con);

//          ScanDAO.translate(con, time_interval);
            ExperimentSc.loadScan(con);

            // STEP 2: Create fingerprint and store them in fingerprint, fp_mac_address.
            // Arguments: scanAmount trashold and Occurance percentage.
            int scanAmount = getScanAmount(con);
            double percent = getPercent(con);

//          FingerprintDAO.create(scanAmount, con, percent);
            ExperimentFp.loadFingerprint(con);

            // STEP 3: Export fingerprint as a *.txt file.
            int simRange   = getSimRange(con);
            String path    = getPath(con);
            FingerprintDAO.export(simRange, path, con);

            // STEP 0: Empty sc_mac_address, scan.
            ScanDAO.empty(con);
            con.close();
            long endTime = System.currentTimeMillis();
            System.out.println("Time: " + (endTime-startTime) + " ms");
        } catch(Exception e) {}
```

FIGURE 5.6: Screenshot from the code of the WifiFingerprintGenerator program.

Once the simulation is completed and values delivering highest success rates of locating sample scan results are determined the "Fingerprint-Generator" component exports the Fingerprints in text and XML formats as shown in Fig. 5.7. The Fingerprint file in text format is then downloaded over HTTP by the Client component.


```
$$$$$$$$$$$$$$$$
*** UR1_GroundFloorStairs2 458 468 Universitaetsring1,1010Vienna_0.png 0 0
3c:08:f6:ca:bc:b0 63 74
58:ac:78:31:b8:c0 78 84
f4:4e:05:0b:e8:40 83 88
08:86:3b:5b:6c:26 90 95
3c:08:f6:9a:bc:60 66 78
44:e4:d9:3e:86:80 87 91
--------------
▼<data>
  ▼<fingerprint name="UR1_GroundFloorStairs2" x="458" y="468" picture="Universitaetsring1,1010Vienna_0.png" var_min="0" var_max="0">
     <signal mac="3c:08:f6:ca:bc:b0" strength_min="63" strength_max="74"/>
     <signal mac="58:ac:78:31:b8:c0" strength_min="78" strength_max="84"/>
     <signal mac="f4:4e:05:0b:e8:40" strength_min="83" strength_max="88"/>
     <signal mac="08:86:3b:5b:6c:26" strength_min="90" strength_max="95"/>
     <signal mac="3c:08:f6:9a:bc:60" strength_min="66" strength_max="78"/>
     <signal mac="44:e4:d9:3e:86:80" strength_min="87" strength_max="91"/>
   </fingerprint>
```


FIGURE 5.7: Screenshot of part of two Fingerprint files containing a location in text and XML format.

The Client component implies the mobile device of the LBS User. It has access to the Database for registration, updating its indoor position (i.e. location), sending sample scan results and inquiring the location of another user (i.e. Client component) marked as friend on the system. The registration is conducted through ZID of the university. More information on this component can be retrieved from Chapter 7.

The nature of indoor location-based services described in the context of this study, which aim to provide a personal assistance to users, dictates that each user and its spatio-temporal behavior is recorded to be utilized during the execution of these services. Since the information on users stored on the server is limited with their user IDs and indoor location data with a time stamp the user data is considered as anonymous enough to prevent any exposure of user privacy by conducting manual analysis on the stored data.

The proposed system does not only protect user's privacy by limitation of user identification to the bare user ID, it also denies users any tools for browsing the database for e.g. the friendship feature. Thus it makes it mandatory for users to know each other personally and to ask for their user IDs because a friendship request can only be received by a valid and registered user. However systems of this nature are open for misuse regarding being utilized as a monitoring tool. Thus a security analysis is strongly encouraged before deployment.

5.1.1 Database

The Database consists of 15 tables as illustrated in Fig. 5.11 from which nine tables are responsible for service realization while the remaining six tables are responsible for the indoor positioning feature.

The tables for service realization are EndUser, LocalUser, EndUserLog, Friend, Admin, Messages, Association and Gcm.

Each Client receives automatically a Google Push Identifier which is stored in the EndUser table. If the Client initiates a registration after approval of its credentials by ZID its user name is paired with its previously stored Google Push Identifier. In case the ZID does not approve the users credentials the system checks whether they can be approved through the LocalUser table where both user name and password are stored.

The EndUserLog table provides a history of locations the user has visited and Google Push Identifiers which were associated to the user.

The Friend table enables clients to befriend each other in order to share their location with each other.

The Admin table contains a list of user names which if approved by ZID can log into the "AdministrationPanel". An Admin can create Messages. The field password does not contain any passwords, instead it indicates with its value whether the Admin is allowed to log in. As a misuse prevention of the messaging feature no messages can be removed and each Message is associated to an Admin.

A Message is addressed to one or more EndUsers.

The list of addressees is stored in Association table.

The data required by Google Cloud Messaging Connection Server for delivery is stored in the Gcm table.

The tables related to the indoor positioning feature are Image, ScanRepository, Generator, scan, sc_mac_address, fingerprint and fp_mac_address.

The Generator table contains settings information of the "FingerprintGenerator", while the ScanRepository table contains all scan result samples from which Fingerprints are generated.

The scan and sc_mac_address tables provide a temporary container for scan results from the ScanRepository table which are selected to be utilized in Fingerprint creation.

The fingerprint and fp_mac_address tables contain fingerprints except the dynamic variation data which is never stored in the Database but generated during the Fingerprinting process and made available to Clients in text and XML format.

The Image table contains association of Fingerprints and images on the server. This information is utilized at the last stage of the Fingerprint generation to provide Client devices with the list of images available and the position of locations on these images.

5.1.2 Web Services

The interfaces have been provided with RESTful Web Services.

There are overall five web services which can be accessed through the URL `http://ilbs.cs.univie.ac.at/service/` as shown in Fig. 5.8.

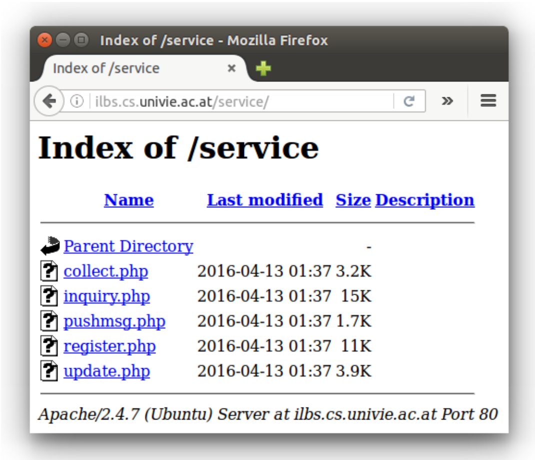

FIGURE 5.8: Screenshot of the URL in browser containing the list of RESTful Web Services.

These web services are not protected by any security measure e.g. HTTPS. The main reason for the lack of this protection is that the user credentials provided by the university are required to be entered only once during the registration process.

The Google Push Messaging Identifier is utilized for unique identification of users and for messaging purpose. As this identifier is not only application specific but also volatile as it changes after each re-install of the application. Furthermore as the system and its processes are isolated from other university related processes, this identifier can not be used out of intended purpose.

Although there is no implementation specifically designed to prevent any misuse of the identifiers, the system provides logs which allows such an extension to be build in the future.

Community Services

There are three web services relevant for this feature; "update" (i.e. location update), "register" and "inquiry".

The update service call requires Google Push Messaging Identifier (i.e. end_user_regid), location and date information. The service call is conducted as e.g.

```
http://ilbs.cs.univie.ac.at/service/update.php
?end_user_regid=STRING&end_user_location=STRING
&end_user_date=YYYY-MM-DD%20hh:mm:ss
```

The register service call requires Google Push Messaging Identifier (i.e. end_user_regid), user account name and password. The call can be conducted as e.g.

```
http://ilbs.cs.univie.ac.at/service/register.php
?end_user_regid=STRING&end_user_id2=STRING
&user_password=STRING
```

The inquiry service call requires operation name, Google Push Messaging Identifier (i.e. end_user_regid) and for operations involving other users the account name of the other user. The service call can be conducted as e.g.

```
http://ilbs.cs.univie.ac.at/service/inquiry.php
?operation=STRING&end_user_regid=STRING&end_user_id2=STRING
```

Valid operations of inquiry service are; "showFriendList", "addFriend", "confirmFriend", "removeFriend" and "showPendingFriendList". An example output for "showFriendList" operation looks as in Fig. 5.9.


```
▼<people>
  ▼<person>
     <id>a[redacted]7</id>
     <name/>
     <location>WHR29_GroundFloorBeforeEnterance</location>
     <date>2016-04-29 20:22:28</date>
   </person>
 </people>
```


FIGURE 5.9: Screenshot of the response for a showFriendList operation in XML format.

Outputs for "confirmFriend", "removeFriend" and "addFriend" contain a standard message regarding the executed operations outcome.

Traffic Telemetrics

The relevant web service for this feature is "collect". The service "collect" is called from Client devices to send sample scan results which are to be utilized by the "FingerprintGenerator", thus it supports the indoor positioning feature. This service call requires Google Push Messaging Identifier (i.e. scan_end_user_regid), date, location and the scanned signals with each signal followed by its signal strength totaling maximum 100 signals and signal strengths. The service call can be conducted as e.g.

```
http://ilbs.cs.univie.ac.at/service/collect.php
/scan_end_user_regid/scan_end_user_date/scan_end_user_location
/scan_mac_address/scan_strength/scan_mac_address/scan_strength
```

Mobile Marketing

The relevant web service for this feature is "pushmsg" and requires message content, server key and maximum 700 Google Push Messaging Identifier (i.e. scan_end_user_regid). The service call can be conducted as e.g.

```
http://ilbs.cs.univie.ac.at/service/pushmsg.php
/message_content/server_key/end_user_regid/end_user_regid/
```

Toll Systems

The relevant web services for this feature are "update" (i.e. location update) and "register". A record of locations visited by users is kept in Database in the table "EndUserLog" from which desired information on attendees of a room can be derived.

5.2 Implementation and Deployment

The web services are implemented in PHP and deployed on an `Apache/2.4.7 (Ubuntu)` server with `php5-curl`,`php5-imap` and `php5-mysql` enabled. The code has been developed in NetBeans IDE.

The implementation can be found on the website `http://ilbs.cs.univie.ac.at/` of this study and the related code is located in website project in the `/service/` folder.

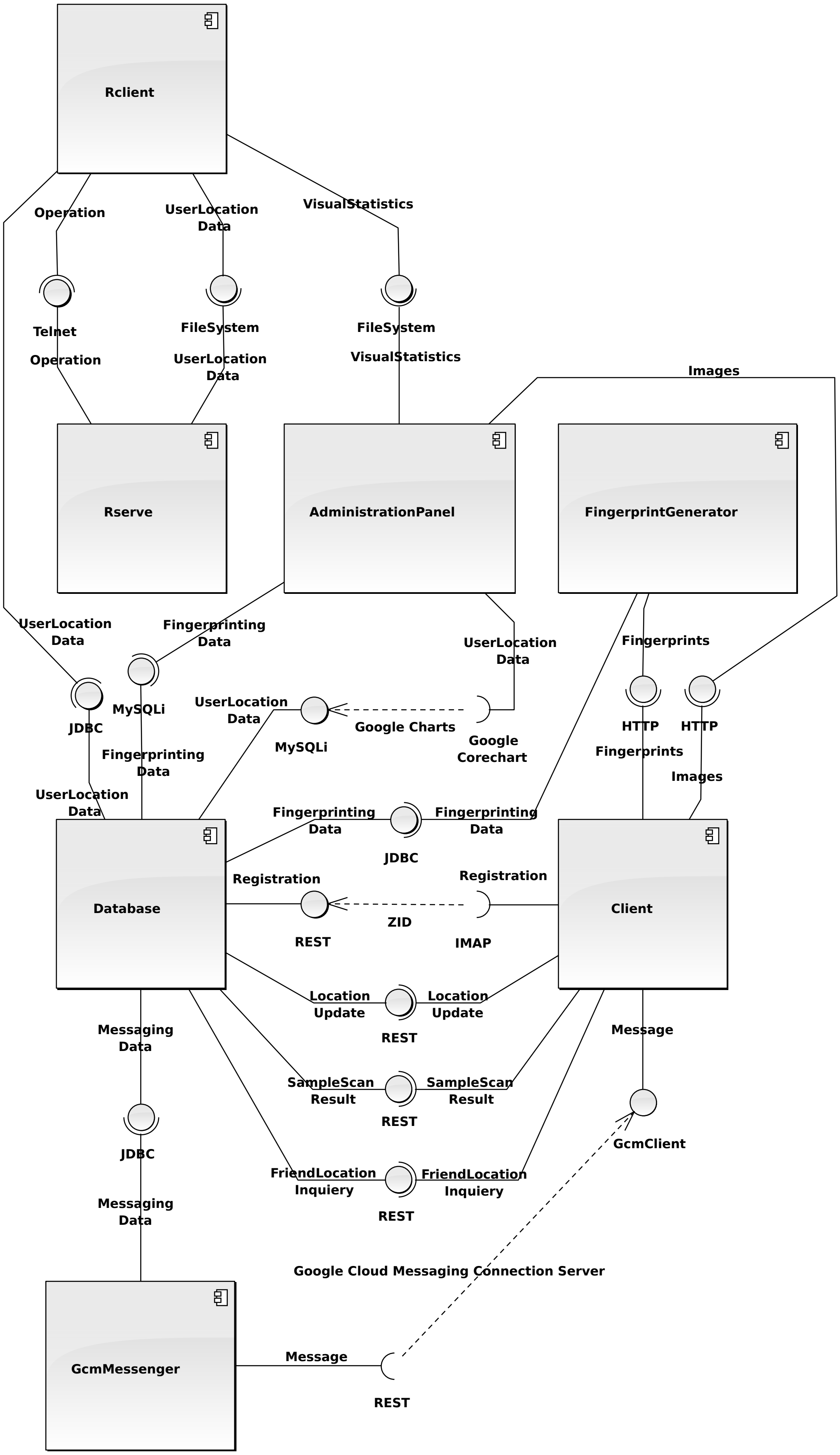

FIGURE 5.10: Component Diagram of the Indoor LBS implementation generated with the program "Software Ideas Modeler by Dušan Rodina"

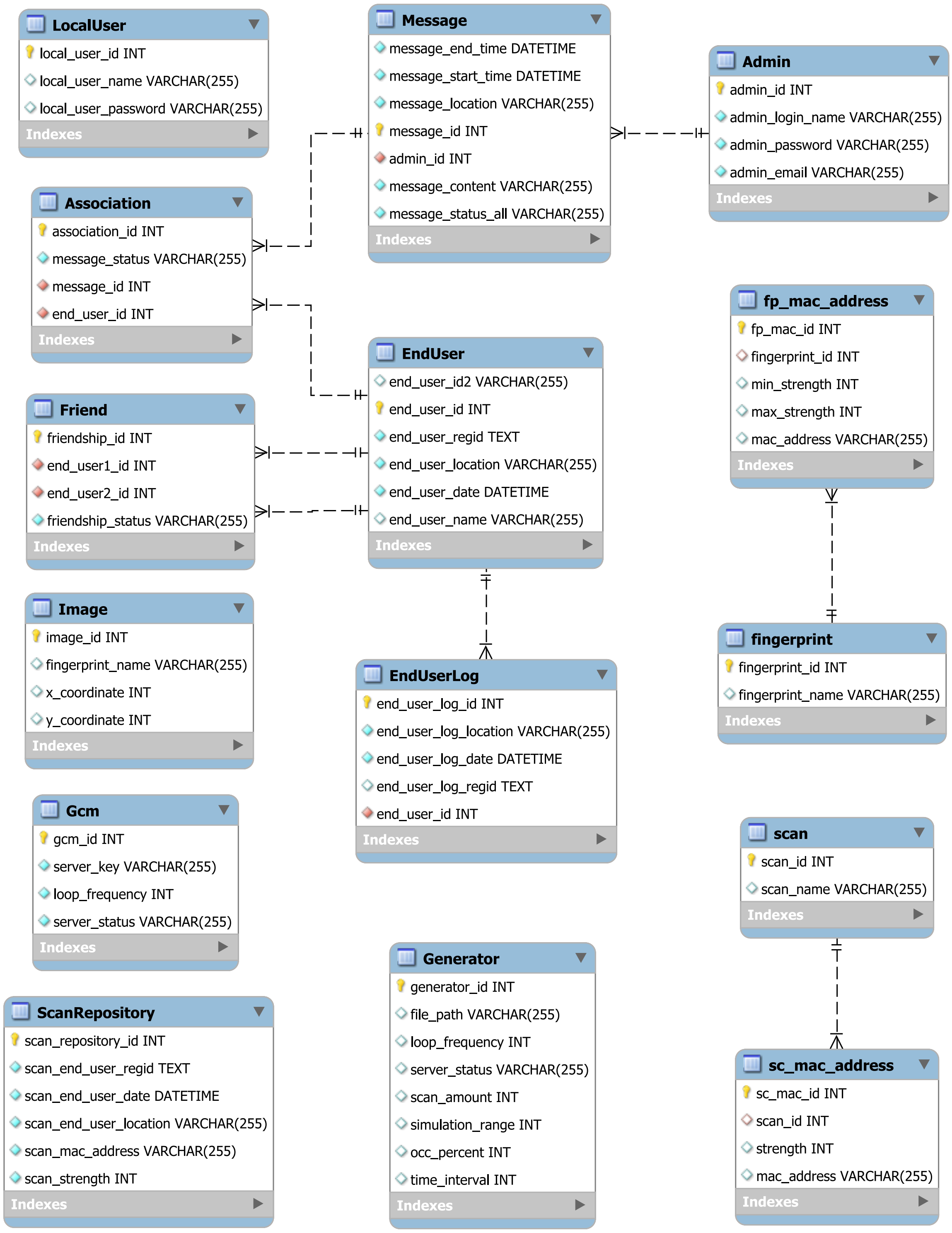

FIGURE 5.11: ER Diagram of the Indoor LBS implementation's database generated with the program "MySQL Workbench".

6 Implementation of the Administration Panel and Analytics

This chapter provides on overview on the implementation of the Administration Panel and analytics. It is important to note that as template for the implementation the design of the website `https://cewebs.cs.univie.ac.at/` has been used.

6.1 Features for LBS Users

The only feature implemented for LBS Users is "Traffic Telemetrics" which not only supports the indoor positioning algorithm running on Client devices but also provides an interface to extend its positioning capability by adding new locations to the system.

6.1.1 Traffic Telemetrics

The Traffic Telemetrics feature has been implemented on the "Settings & More" page of the Administration Panel. The feature "Upload Images" - allowing Admins to add new floor plans- as a part of Traffic Telemetrics features is illustrated on the screen shot in Fig. 6.1.

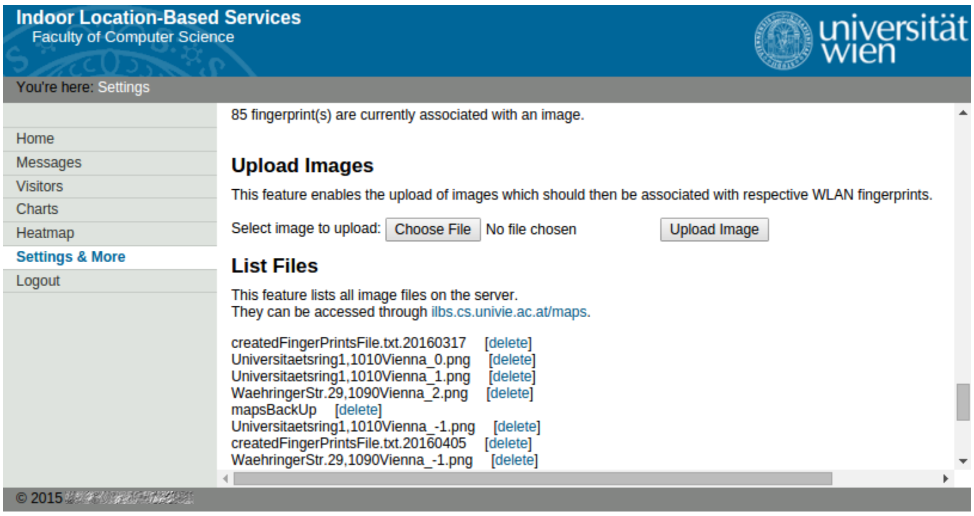

FIGURE 6.1: Screenshot of the "Settings & More" page showing "Upload Images" feature for Traffic Telemetrics implementation.

The other two features related to Traffic Telemetrics are "Fingerprint Generator Images" (responsible for association of images and Fingerprints) and "Fingerprint Generator Settings" (responsible for creation and update of Fingerprints).

6.2 Features for Research and Development

The feature implemented for Research and Development is "Toll Systems" with the aim to give its users the possibility to collect enough data on which Business Intelligence methods can be applied in order to cover up correlations in user behavior.

6.2.1 Toll Systems

The Toll Systems feature consists of two services, i.e. location tracker and analytics. The aim of the Location tracker feature is providing an interface for automated attendance tracking to classes. It provides the "Room History" and the "Visitor History" features illustrated on the screen shot in Fig. 6.2.

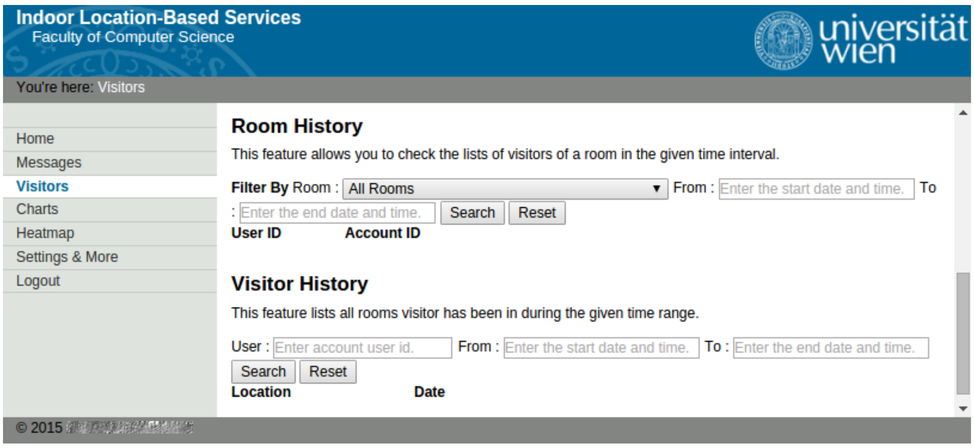

FIGURE 6.2: Screenshot of "Visitors" page showing two of the location tracking features.

There are two analytics features to visualize users' spatio-temporal behavior, i.e. area charts and heat map. The two area charts based on Google Charts API visualize the daily room population e.g. as shown on Fig. 6.3 and time spent by a user in rooms (i.e. locations mapped by the indoor positioning system).

The heat map visualizes through the R program the level of utilization of each room by each user and clusters users with similar spatio-temporal behavior. The more or longer a room is utilized the lighter is the box in the intersection with the room's name. The user who utilized it is marked as shown on the screen shot in Fig. 6.4. Unlike the charts the heat map visualizes only overall utilization and is updated at an hourly rate.

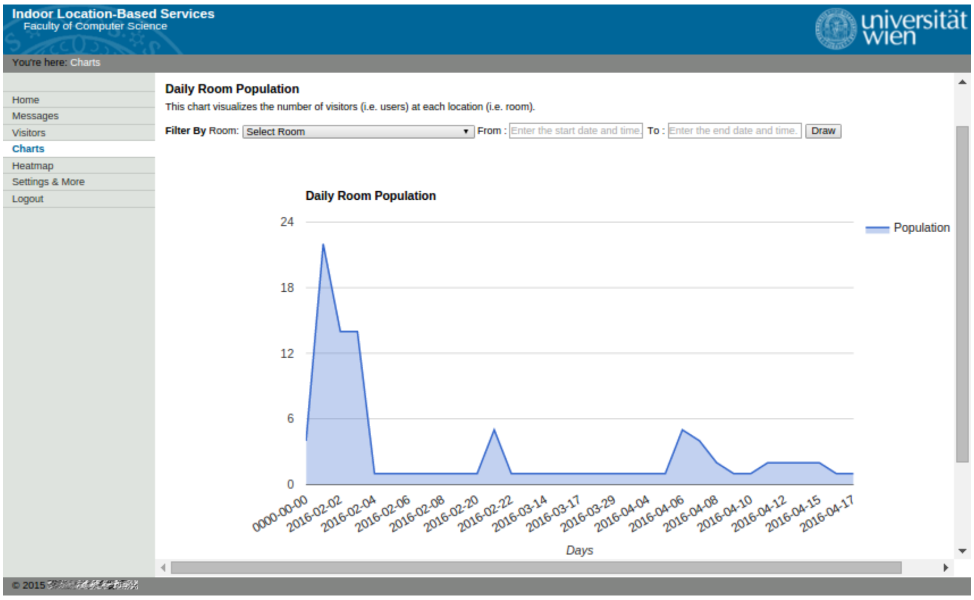

FIGURE 6.3: Screenshot of the Daily Room Population Chart visualizing the number of visitors at all locations in different days.

6.3 Features for Content Provider

The feature implemented for Content Providers is the "Mobile Marketing" service. The implementation on the Administration Panel consists of an interface to manage and operate the "GcmMessenger" application running on the server.

6.3.1 Mobile Marketing

The "Mobile Marketing" service which basically is a time and location triggered messaging feature consists of two parts,i.e. "Google Cloud Messaging Settings" implemented in the "Settings & More" page and "Send Message", "Recipients" and "Messages" features implemented in the "Messages" page. The "Send Message" feature is illustrated on the screen shot in Fig. 6.5.

6.4 Implementation of the Administration Panel

Besides the template specific elements e.g. images and CSS code acquired from the website `https://cewebs.cs.univie.ac.at`
the implementation is made in HTML, PHP and JavaScript and follows strictly the Model-View-Controller pattern. The credentials required for the MySQL connection are stored in the file `password.php` which needs to be edited manually to edit the MySQL user credentials. The credentials for a `root` user is hard-coded in the `/controller/login.php` file. The code has been developed in NetBeans IDE.

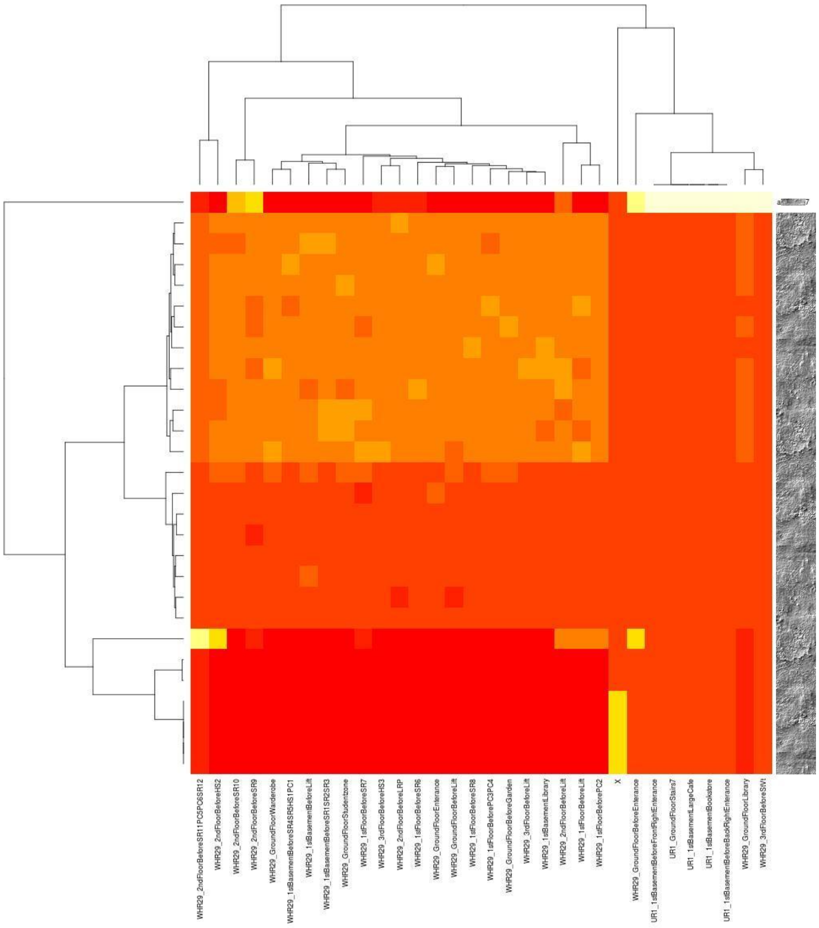

FIGURE 6.4: Heatmap shown on the "Heatmap" page.

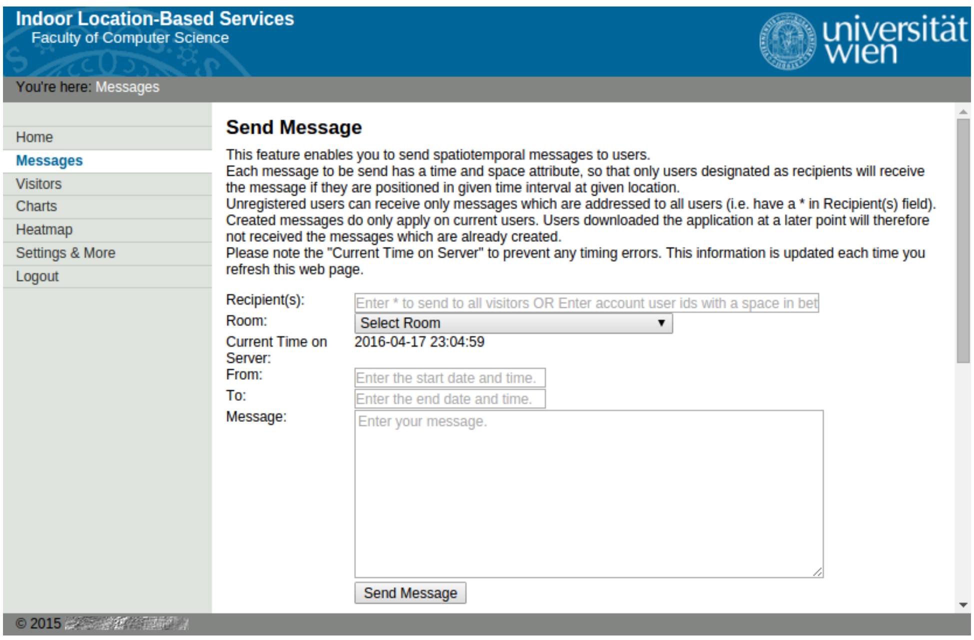

FIGURE 6.5: Screenshot of Messages page showing "Send Messages" feature.

7 Implementation of the Mobile Application

The mobile application is the "Client" component of the proposed architecture. The implementation in this study has been made for Android devices with API levels 14+ only and can be downloaded from Google Play Store by searching for "IndoorLBS" application.

7.1 Features for LBS User

The features for LBS User in the mobile application defines the total interaction a user can have through the graphical user interface of the application. These features are "Community Services" and "Traffic Telemetrics".

It is important to note that although the messaging feature is to be consumed by the LBS User it is associated with the Content Provider as it provides an interface for the Content Provider to interact with LBS Users.

7.1.1 Community Services

Community Services consist of registration and friendship features of the mobile application.

The LBS User can access the registration feature directly from the main layout as illustrated on the screen shot in Fig. 7.1.

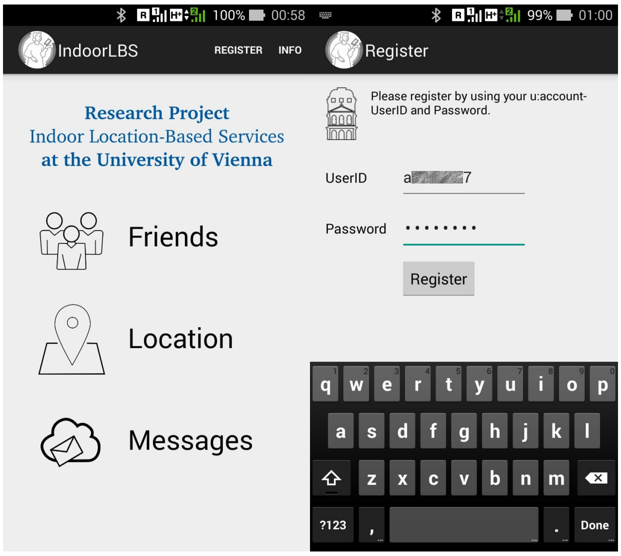

FIGURE 7.1: Screenshot of the "Main Layout" (left) and the "Registration" feature (right) from the Android mobile application.

After successful registration and getting approval of the other LBS User which has been added as a friend the LBS User can now see indoor location of the befriended user as shown in Fig. 7.2.

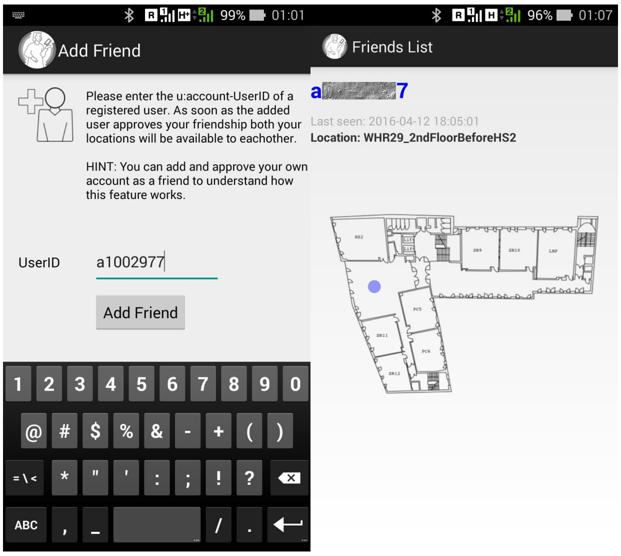

FIGURE 7.2: Screenshot of the "Add Friend" (left) and the location sharing feature (right) from the Android mobile application.

7.1.2 Traffic Telemetrics

Traffic Telemetrics feature provides LBS User with indoor positioning information and with information on infrastructure located at the same floor as the LBS User.

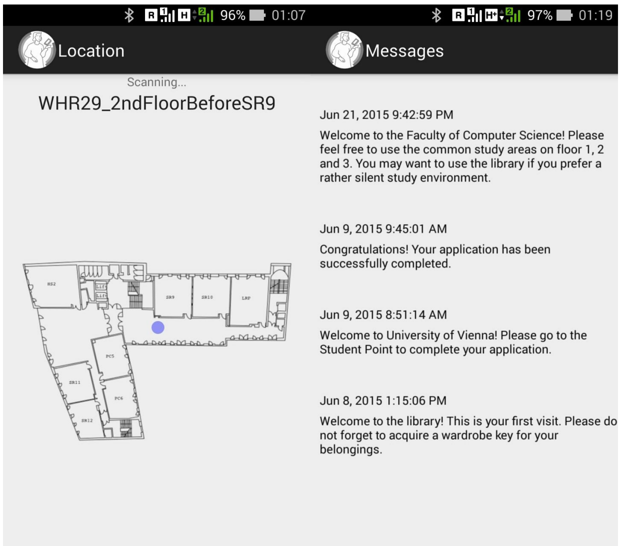

FIGURE 7.3: Screenshot of the "Location" (left) and "Messages" (right) feature from the Android mobile application.

Once the location is calculated it is written on the screen and visually represented on the floor map as illustrated on screen shot in Fig. 7.3 (left) which also contains the information on infrastructure at that floor e.g. seminar rooms and cafés.

7.2 Features for Research and Development

The feature implemented for Research and Development is the location tracking function.

7.2.1 Toll Systems

The location tracking feature works basically as a beacon transferring its location data every 15 seconds to the server.

There is the possibility that the implemented IPS may contain an error regarding users calculated position, e.g. by showing the user in another room close-by to its real indoor location. Users can add themselves as friend on the system to see their last updated location on the server.

7.3 Features for Content Provider

The feature for Content Providers is implemented as a listener for incoming Google Push Messages.

7.3.1 Mobile Marketing

Each message received from the system is shown with a notification once it reaches the users mobile device. Messages are also automatically stored in a local database of the users device so that they can be read at a later time as illustrated on the screen shot in Fig.7.3 (right).

7.4 Implementation Notes

As stated in Delaney, Jayant, and Simunic (2003) WLAN access points when idle send signals with 100 ms delay. Based on the number of utilized WLAN channels which is given as 14, the scan time has been selected as 1500 ms to assure that all signals from access points can be captured.

The location update occurs only at every 15 seconds to prevent excessive battery usage. The scan speed is set to 1500 ms when the user utilizes "Location" feature to see the own indoor position.

The application sends a sample scan result with its calculated location to the server every 15 seconds provided its accelerometer reading indicates that it is not moving and it is located in a mapped area.

The code has been adapted to this change in a way that it sends its location to the server at a constant rate of every 15 seconds even when the positioning frequency increases to 1.5 seconds while "Location" feature is called by the user. The update speed is critical as it is utilized to compute the time spent by the user in a room by counting the location updates the user invoked from that room in a given time interval. The code shown in

```java
        @Override
        protected void onPostExecute(String nURL) {
            if(Utils.internetConnection(getBaseContext())
                    && isConnectedToServer()) {
                try{
                    XMLParser parser = new XMLParser();

                    if(session.getInt("scanInterval")<15000) {
                        if(session.getInt("updateCounter")<10) { // 15000/1500=10
                            int c = session.getInt("updateCounter");
                            c++;
                            session.put("updateCounter", Integer.toString(c));
                        } else {
                            session.put("updateCounter", "0");
                            @SuppressWarnings("unused")
                            String xml = parser.getXmlFromUrl(nURL);
//                          Log.d(TAG, "Updating Location.. Resetting Counter.. ");
                        }
                    } else {
                        @SuppressWarnings("unused")
                        String xml = parser.getXmlFromUrl(nURL);
//                      Log.d(TAG, "Updating Location.. ");
                    }


                } catch(Exception e) {
//                  Log.d(TAG, "Something went wrong while parsing.. ");
                }
            }
        }
    }.execute(null, null, null);
}
```

FIGURE 7.4: Screenshot of the code from ScanService.java responsible for regulation of the Location Update Frequency.

Fig. 7.4 reveals the `try-catch` block used to fix the update time to 15 seconds. As the code here refers to an asynchronized method, the duration can technically not be guaranteed to be exactly 15 seconds.

All location related data is processed in the application through `session`. The SessionManager class is responsible for storing calculated location information, information on scan frequency and information on current time. At the end of each hour the Fingerprints file is downloaded and image files are checked to reveal if a new image file is required for one of the fingerprinted locations.

The code has been developed in Eclipse IDE.

8 Extensibility and Interoperability

This chapter embodies information regarding implementation of a new functionality with minimal changes in the code of the proposed system. It also discusses possibilities for interoperability of other applications with the current features offered by the implementation.

8.1 Extensibility

The proposed architecture is designed to be extended with minimal changes in the code of the mobile application and the Administration Panel.

8.1.1 Mobile Application

New features can be implemented in the mobile application by editing the menu item "Register" to provide the user with a detailed control panel for the features planned to be implemented as shown in Fig. 8.1. This control panel would indicate which other services the user prefers to register e.g. virtual tour guide, virtual assistant or exam location reminder.

FIGURE 8.1: Screenshot of the Main layout containing a ListView layout "Messages" and the Menu item "Register".

Furthermore new services can be implemented as web applications and linked to the existing ListView layout. These web applications can be called within the Android application with the Google Notification Identifier.

8.1.2 LBS

The location-based Services can be extended with third party systems where user spatio-temporal data can be linked to further user information an be utilized to provide personalized assistance.

Any application deployed to extend LBS can send messages to LBS users simply by calling the web service through `/service/pushmsg.php` with the server key, message and a list of recipients' Google Notification Identifiers.

8.2 Interoperability

The Fingerprints generated by the indoor positioning algorithm are provided to LBS Users both in text and XML formats. Although the XML format provides a ubiquitous parsing possibility the Android application implemented within this study utilize the Fingerprints in text format. The main reason for this is the overhead of XML files created by tags which increases the file size that needs to be downloaded at an hourly basis. However Fingerprints provided in XML format allow the creation of a Fingerprint database compiled from multiple deployments of this system by different organizations with ease.

9 Evaluation

In this chapter the level of accuracy which can be achieved with the proposed indoor positioning algorithm based on WLAN (i.e. WiFi) Fingerprinting has been evaluated in order to prove that the achieved level of accuracy is sufficient for the realization of indoor location-based services.

9.1 Evaluation Criteria

The evaluation of the proposed system comprises three aspects (i.e. criteria):

- the effectiveness of the indoor positioning algorithm,
- the effectiveness of the implemented location-based services
- the perception of "LBS Users" and "Content Providers" as well as "Research and Development" actors in regard to the usefulness of the implemented indoor location-based services.

At first, the effectiveness of the indoor positioning algorithm was evaluated conducting an on-site test. The aim of the test was to assess whether the "Location" feature of the developed "Mobile Application" could locate the user inside a building of the University of Vienna. The data collected from the on-site test has been re-evaluated through the simulation program written within this study.

Secondly, the effectiveness of the implemented location-based services have been tested through the implemented "Administration Panel" and the "Mobile Application". Both of these evaluations have been conducted as functional tests with an evolutionary testing technique which was executed manually.

Lastly, the perception of "LBS User"s and "Content Provider"s & "Research and Development" actors was evaluated using two specially designed surveys allowing them to reflect their thoughts on respective services. Students currently enrolled at the University of Vienna have been designated as the "LBS User" and the lecturers & research personnel as "Content Provider"s & "Research and Development" actors.

9.2 Evaluation Results

The developed indoor positioning algorithm achieved the accuracy of 95% for room-level precision, i.e. the distance between two Fingerprint is at minimum three meters and at maximum six meters.

The on-site test has been conducted at the premises of Faculty of Computer Science, University of Vienna and the result has been recorded on video `https://youtu.be/CwEp2NzYlwA`.

The indoor location-based services implemented within this study were evaluated by 17 students currently enrolled at the University of Vienna regarding their usefulness. The evaluation was conducted in form of an interview and students were asked to give points for features (i.e. functionality) listed in Table 9.1 by filling an online survey.

TABLE 9.1: Association of the functionality implemented within this study to the respective LBS feature and its explanation.

Functionality	LBS	Explanation
Friends	Community Services	Location Sharing
Location	Traffic Telemetrics	Navigation Assistance
Messages	Mobile Marketing	Spatio-temporal Notification
Attendance Tracking	Toll Systems	Automated Attendance Tracking

The survey result containing weighted averages for each service from the LBS User's perspective is illustrated on a radar plot in Fig. 9.1.

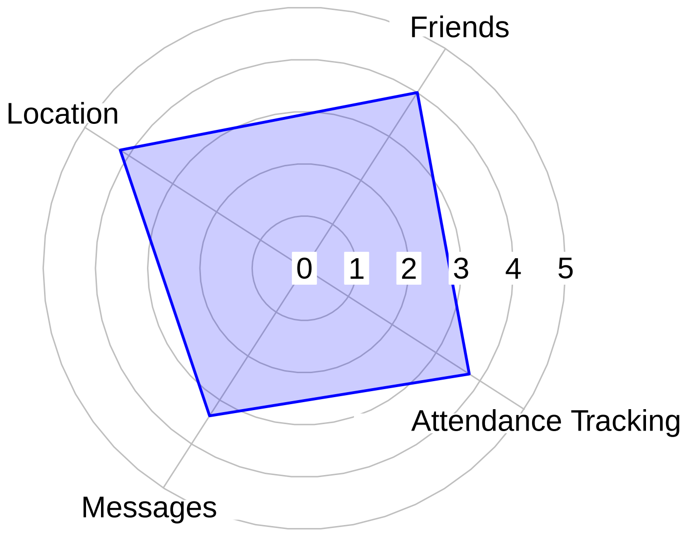

FIGURE 9.1: Perception of 17 students on usefulness of the IndoorLBS application for 4 different features (Evaluation schema; -2: not at all useful, 2: extremely useful).

The most useful feature designated by the students is "Location" and "Friends" with weighted averages of 4.19 and 4.00, while "Attendance Tracking" and "Messages" features had similar weighted averages (3.75 and 3.63).

The Net Promoter Score introduced in Reichheld (2003) in the range between -100 and 100 is evaluated by students as 24. While 50.00% of students found the graphical user interface of the application "Extremely user-friendly", 50.00% of students evaluated it as "Very user-friendly".

Comments of Students on the survey and my reflections are as follows:

> `add a friend -> would be better to search a friend by name either, because do you know the matriculation number of your friends? maybe you should offer the possibility to change the language of the interface in other languages.`
>
> The main reason behind the decision for not providing a browsing feature was to protect users' privacy. Thus implementation of this feature is discouraged. Since the proposed system is not at production stage and is implemented as a part of this study no localization has been conducted for the sake of simplicity. Future implementations are however encouraged to provide a localization feature.
>
> `I think it's a great and creative idea!`
>
> -
>
> `Great design and graphics, a simple and user-friendly application!`
>
> -
>
> `Automated attendance Tracking is a nice idea, but I worry about data Security and data abuse`
>
> The implemented Attendance Tracking utilizes the bare minimum of user data to fulfill its objective. A further measure can be undertaken by denying the administrators from accessing any real-time user data through the "AdministrationPanel".
>
> `really nice. Keep on working.`
>
> -
>
> `It's a nice idea, but I would rather use other messengers to communicate with my friends :)`
>
> This comment indicates that the feature "Messages" was not well understood by some of the users, which might also explain the reason why it was designated as the least useful feature. "Messages" is a tool which allows messages from the administrators to be received by students instantly. It provides a one-sided communication. The name "Messages" is encouraged to be changed as e.g. "Notifications" for better understanding of this feature.

The "AdministrationPanel" was evaluated by three lecturers in form of an interview finalized with an online survey. The results are visualized in Fig. 9.2. The most useful features designated by lecturers are "Messages" and "Charts" both with an average weight of 3.67 while "Heatmap" has an average weight of 2.67 and "Visitors" 2.33. "Heatmap", "Charts" and "Visitors" are part of the service "Toll Systems". "Messages" is part of the service "Mobile Marketing".

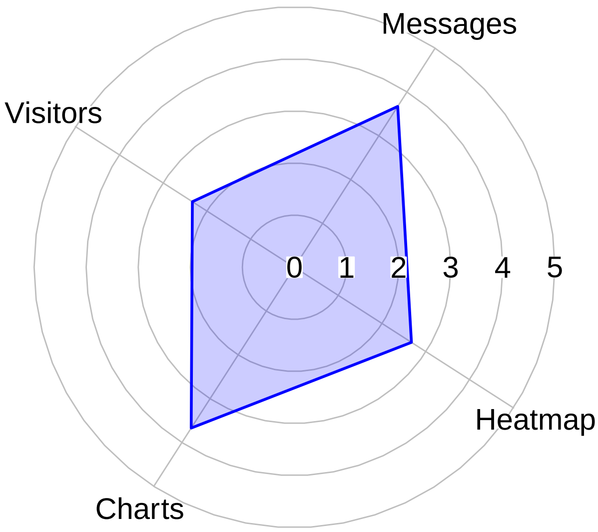

FIGURE 9.2: Perception of 3 lecturers on usefulness of the indoor LBS for 4 different features (Evaluation schema; -2: not at all useful, 2: extremely useful).

It is interesting to see that the feature "Messages" which is evaluated by students as least useful is designated by lecturers as most useful feature. The feature "Visitors" (i.e. Attendance Tracking) which is evaluated by lecturers as least useful feature is designated by students as the third useful feature with a very similar average weight to the second useful feature "Friends".

The Net Promoter Score in the range between -100 and 100 is evaluated by lecturers as -100.

While 66.67% of lecturers found the information on the website "Very easy" to understand 33.33% of lecturers found the information as "Somewhat easy" to understand.

Comments of Lecturers on the survey and my reflections are as follows;

```
Heatmaps eher basierend auf den Karten darstellen.  Daher
z.B. die Raeume einfaerben entsprechend in den verwendeten
Karten.  Zoomfunktion bei den Karten um diese vergroessern
zu koennen.
```

One of the objectives of this study was to create a system which is easy to deploy and requires the bare minimum manual involvement. No changes regarding heat maps such as projection of heat maps on floor plans are encouraged in order to keep the system as automatized as possible and extensible with minimum manual interference.

```
From a data collection point of view, I think this app
is very interesting, but as a user I would not feel
too well that all my spatial information (when I have
been where) are being collected and analyzed.
```

A part of this comment is written from students point of view and a similar comment by a student has already been addressed above.

```
Connection to Cewebs and or UFind would be nice.  Rename
"Message" to "News or Updates".
```

A connection to CEWebS the e-learning platform and/or U:Find system of the university in a future implementation is encouraged. Also the feature "Messages" should be renamed as suggested in this comment to prevent any misunderstanding by both students and lecturers. Such a misunderstanding can already be seen by one of the comments from students.

10 Conclusion

Location-based services are intended to assist users in their daily life by providing context aware information regarding their whereabouts. As stated in Costilla-Reyes and Namuduri (2014) there are no ubiquitous positioning techniques satisfying the precision and infrastructure requirements for indoor positioning, therefore the aim of this study was to design and to implement an efficient system providing indoor positioning and indoor location-based services at a satisfactory level for LBS Users at an university environment. As mentioned especially in the architectural design in Chapter 5 of this thesis, privacy is a major challenge for the use of this type of systems and certainly needs a more detailed analysis.

This study has shown that WLAN Fingerprinting can provide reliable accuracy at 95% success rate in room-level precision in a range of 3 to 6 meters for realization of indoor positioning and indoor location-based services. The proposed algorithm has been derived from Hansen et al. (2010) which was partially based on assumptions in visitor circulation and manual volunteer user interference for correction of Fingerprints. An example procedure in regard to the design of the indoor location-based services and their implementation has been presented in this study.

The perception of LBS Users on the implemented indoor location-based services have been proved to be positive as indicated from the Net Promoter Score as 24 in the range from -100 to 100.

As a future work the proposed algorithm should be improved with outlier detection features to limit extreme changes in measured signal strengths while sampling signal results for Fingerprint generation.

During the field test of the algorithm it was noticed that at border locations between two areas the calculated position was swinging at each scan between two neighboring areas. This issue should be handled by utilizing statistical methods which will determine users location based on e.g. the last four location calculations.

Furthermore the algorithm should be tested with devices equipped with different antenna sizes to better understand the effects of signal reception performance of devices on positioning and adjusted accordingly.

Other sensors such as compass and gyroscope can be utilized to provide additional navigation assistance to the current algorithm to provide increased precision in positioning.

A Deployment Instructions

This appendix provides information on the deployment of the server components. It is assumed that a fresh installation of Ubuntu 14.04.3 LTS is provided on a machine with a minimum 2.0 GHz CPU and 8 GiB RAM. Please do not forget to update and upgrade packages after booting your machine for the first time.

Throughout this document it is assumed that the user name is `administrator`.

The first step contains installation and configuration of MySQL and Apache Server through executing the code below as root:

```
apt-get install mysql-server mysql-client
apt-get install apache2
apt-get install php5 libapache2-mod-php5
service apache2 restart
apt-get install php5-mysql php5-curl php5-gd php5-intl php-pear
php5-imagick php5-imap php5-mcrypt php5-memcache php5-ming
php5-ps php5-p
apt-get install php5-mysql php5-curl php5-gd php5-intl php-pear
php5-imagick php5-imap php5-mcrypt php5-memcache php5-ming
php5-ps php5-spell php5-recode php5-snmp php5-sqlite php5-tidy
php5-xmlrpc php5-xsl openssl
apt-get install php5-mysql php5-curl php5-gd php5-intl php-pear
php5-imagick php5-imap php5-mcrypt php5-memcache php5-ming
php5-ps php5-pspell php5-recode php5-snmp php5-sqlite php5-tidy
php5-xmlrpc php5-xsl openssl
service apache2 restart
apt-get install php5-xcache
service apache2 restart
apt-get install php5-xcache
service apache2 restart
sudo apt-get install php5-imap
sudo php5enmod imap
sudo service apache2 restart
php -m|grep imap
sudo /etc/init.d/apache2 restart
sudo service apache2 restart
sudo chmod 777 /etc/php5/ -R
sudo service apache2 restart
```

In the next step the Java 1.8 Virtual Machine is installed through a third party and its version checked by executing following commands:

```
sudo add-apt-repository ppa:webupd8team/java
sudo apt-get update
sudo apt-get install oracle-java8-installer
java -version
```

To install the R program execute following commands:

```
sudo apt-get install r-base sudo apt-get install r-base-core
```

After installing the "Rserve" package through cran execute following commands to enable shlib and check if the R server is online:

```
R CMD Rserve
R -enable-R-shlib
telnet localhost 6311
```

Create a database `ilbs` in MySQL and create following tables:

```sql

CREATE TABLE Admin(
admin_id integer AUTO_INCREMENT NOT NULL,
admin_login_name VARCHAR(255) NOT NULL,
admin_password VARCHAR(255) NOT NULL,
admin_email VARCHAR(255) NOT NULL,
PRIMARY KEY(admin_id)
);

CREATE TABLE Message(
message_end_time DATETIME NOT NULL,
message_start_time DATETIME NOT NULL,
message_location VARCHAR(255) NOT NULL,
message_id integer AUTO_INCREMENT NOT NULL,
admin_id integer NOT NULL,
message_content VARCHAR(255) NOT NULL,
message_status_all VARCHAR(255) NOT NULL,
PRIMARY KEY(message_id),
FOREIGN KEY(admin_id) REFERENCES Admin(admin_id) ON
    UPDATE CASCADE
);

CREATE TABLE EndUser(
end_user_id2 VARCHAR(255),
end_user_id integer AUTO_INCREMENT NOT NULL,
end_user_regid TEXT NOT NULL,
end_user_location VARCHAR(255) NOT NULL,
end_user_date DATETIME NOT NULL,
end_user_name VARCHAR(255),
PRIMARY KEY(end_user_id)
```

```
);

CREATE TABLE Association(
association_id integer AUTO_INCREMENT NOT NULL,
message_status VARCHAR(255) NOT NULL,
message_id  integer NOT NULL,
end_user_id integer NOT NULL,
PRIMARY KEY(association_id),
FOREIGN KEY(message_id) REFERENCES Message(message_id),
FOREIGN KEY(end_user_id) REFERENCES EndUser(end_user_id)
);

CREATE TABLE EndUserLog(
end_user_log_id integer AUTO_INCREMENT NOT NULL,
end_user_log_location VARCHAR(255) NOT NULL,
end_user_log_date DATETIME NOT NULL,
end_user_log_regid TEXT,
end_user_id integer NOT NULL,
PRIMARY KEY(end_user_log_id),
FOREIGN KEY(end_user_id) REFERENCES EndUser(end_user_id)
);

CREATE TABLE Friend(
friendship_id integer AUTO_INCREMENT NOT NULL,
end_user1_id integer NOT NULL,
end_user2_id integer NOT NULL,
friendship_status VARCHAR(255) NOT NULL,
PRIMARY KEY(friendship_id),
FOREIGN KEY(end_user1_id) REFERENCES EndUser(end_user_id),
FOREIGN KEY(end_user2_id) REFERENCES EndUser(end_user_id)
);

CREATE TABLE LocalUser(
local_user_id integer AUTO_INCREMENT NOT NULL,
local_user_name VARCHAR(255),
local_user_password VARCHAR(255),
PRIMARY KEY(local_user_id)
);

CREATE TABLE Gcm(
gcm_id integer AUTO_INCREMENT NOT NULL,
server_key VARCHAR(255) NOT NULL,
loop_frequency integer NOT NULL,
server_status VARCHAR(255) NOT NULL,
PRIMARY KEY(gcm_id)
);
```

```

CREATE TABLE ScanRepository(
scan_repository_id integer AUTO_INCREMENT NOT NULL,
scan_end_user_regid TEXT NOT NULL,
scan_end_user_date DATETIME NOT NULL,
scan_end_user_location VARCHAR(255) NOT NULL,
scan_mac_address VARCHAR(255) NOT NULL,
scan_strength integer NOT NULL,
PRIMARY KEY (scan_repository_id)
);

CREATE TABLE fingerprint(
fingerprint_id integer AUTO_INCREMENT,
fingerprint_name varchar(255),
Primary Key(fingerprint_id)
);

CREATE TABLE fp_mac_address(
fp_mac_id integer AUTO_INCREMENT,
fingerprint_id integer,
min_strength integer,
max_strength integer,
mac_address varchar(255),
Primary Key(fp_mac_id),
Foreign Key(fingerprint_id) references fingerprint(
    fingerprint_id)
);

CREATE TABLE scan (
scan_id integer AUTO_INCREMENT,
scan_name varchar(255),
Primary Key (scan_id)
);

CREATE TABLE sc_mac_address (
sc_mac_id integer AUTO_INCREMENT,
scan_id integer,
strength integer,
mac_address varchar(255),
Primary Key (sc_mac_id),
Foreign Key (scan_id) references scan(scan_id)
);

CREATE TABLE Generator (
generator_id integer AUTO_INCREMENT,
file_path varchar(255),
loop_frequency integer,
server_status varchar(255),
scan_amount integer,
simulation_range integer,
occ_percent integer,
```

```
time_interval integer,
Primary Key (generator_id)
);

CREATE TABLE Image (
image_id integer AUTO_INCREMENT,
fingerprint_name varchar(255),
x_coordinate integer,
y_coordinate integer,
Primary Key (image_id)
);
```

Copy the web project into the root folder of Apache Server i.e. `/var/www/html/` and change the password in `password.php` file so that it matches the password of MySQL Server.

Execute the command `crontab -e` in shell and add following lines to run the respective scripts on startup:

```
@reboot /home/administrator/GcmMessengerScript.sh
@reboot /home/administrator/WifiFingerprintGeneratorScript.sh
@reboot /home/administrator/RclientScript.sh
```

Copy the shell scripts `GcmMessengerScript.sh`, `WifiFingerprintGeneratorScript.sh` and `RclientScript.sh` into `/home/administrator/`.

Please note that you can alternatively put the content of these scripts into a single script and run only that script on startup. The new script looks in this case as:

```
#/bin/bash
java -jar /home/administrator/GcmMessenger.jar &
java -Xmx7g -jar /home/administrator/WifiFingerprintGenerator.jar
&
/usr/lib/R/bin/R CMD
/home/administrator/R/x86_64-pc-linux-gnu-library/3.0/Rserve/libs//Rserve
-no-save &
```

Please note that the `WifiFingerprintGenerator.jar` requires around 7 GiB RAM to process 85 Fingerprints.

Copy the files `GcmMessenger.jar`, `WifiFingerprintGenerator.jar`, `Rclient.jar`, `Rscript.r` and `Rscript2.r`. Please note that these Java applications are required to be recompiled with the password matching the password of MySQL Server.

Please note that you can create an Administrator `root` manually through MySQL command prompt and log in by entering that user name and the hard-coded password in the PHP file.

B Operation Instructions

For instructions respective usage of services please refer to the explanations on the website. The Operation Instructions in this appendix are about creation and management of Fingerprints.

Provided that the "WiFiFingerprintGenerator.jar" program is running on the server and the Fingerprint Generator's setting is convenient to generate new Fingerprints as e.g. shown on the screen shot in Fig. B.1.

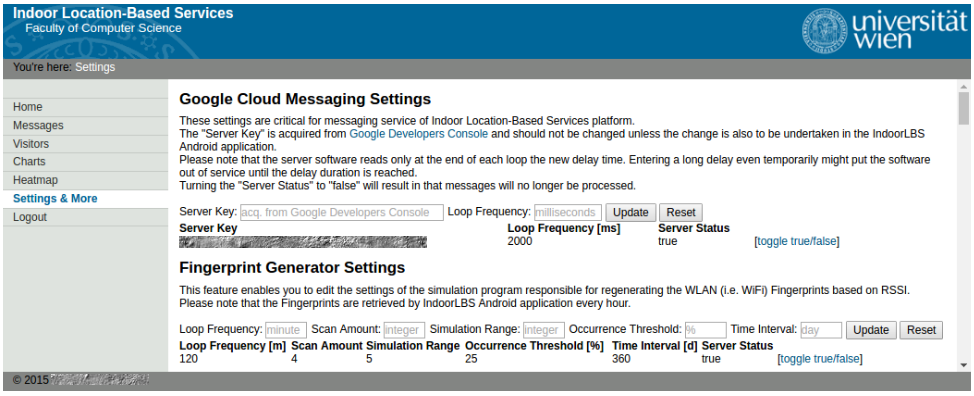

FIGURE B.1: Fingerprint Generator set to create new Fingerprints.

Creation of the Fingerprint for a new location consists of following steps:

1. Scanning Signals at the new Location

   Signals should be scanned by using the Maintenance Application written for Android devices. To prevent misuse of the application the operator is required to enter a password which is to be found on the "Settings & More" page under the title "Maintenance Application" together with the link to download the *.apk file to install the application on an Android device.

   This application enables the operator to scan the WLAN signals in the environment and send them to the server. The operator should stand still during the scan process. Each scan result requires the name of the location where it originates from. It is critical that the amount of scan results created for the location is equal or exceeds the "Scan Amount" value entered in "Fingerprint Generator Settings".

   The operator can read the number of scan results made at the location through the value down below of the screen marked as "null" on the screen shot in Fig. B.2. The application informs the operator before sending the scan results and after the scan results are successfully registered by the server through Toast Messages.

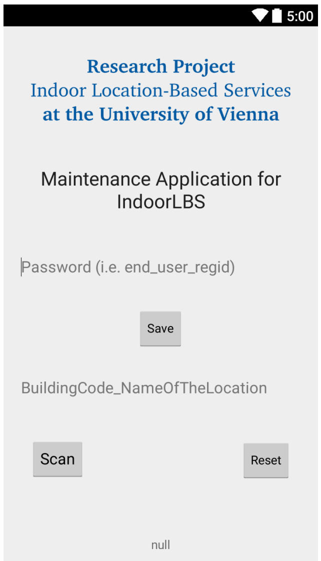

FIGURE B.2: Main Layout of the Maintenance Application.

The operator should take into consideration that signal strengths from access points are weakened if the operators body stands between the WLAN receiver of the Android device and the access point. Thus the scans should be conducted in four directions each with 90 degree difference from its predecessor.

The name of each Fingerprint is required to consist from the combination of a building code and name of the location with an underline "_" in between. It is the responsibility of the operator to make sure that each building has a unique building code.

If the Fingerprint is not generated after the time entered for one loop of the program please make sure that enough RAM is given free for the "WiFiFingerprintGenerator.jar". Keep in mind that the standard heap size of Java is 254 MB which may be insufficient and cause a memory leak error i.e. `java.lang.OutOfMemoryError`. If you are not sure how much memory you should allocate please run the program manually on the terminal and check whether it completes a loop successfully for its current heap size.

It is important to note that the Maintenance Application acts identical to a client which sends sample scan results to the server with the exceptions that it requires the operator to enter the location manually -instead of calculating the position itself as the client application (i.e. mobile application for the LBS User) does- and it is validated as a reliable source through the Google Push Messaging Identifier -same as the client application- which however is entered for the Maintenance

Application manually prior the operation and does not need to be a valid identifier from Google. The operator is then required to enter the identifier set for the Maintenance Application on the main layout before committing scan results to the server. Please do not forget to create a respective entry in the database before trying to use the Maintenance Application.

2. Uploading Floor Plan

The floor plans are required to be uploaded prior to the association of locations (i.e. Fingerprints) and floor plans as a non-existing floor plan would cause the client application to crash.

Uploaded floor plans should be in PNG format and have the size 650x650 pixels with a transparent background. It should be taken under advisement that floor plan names are to consist from the combination of the building address and floor level with an underline "_" in between and ending with ".png".

3. Associating Location to Floor Plan

The association of locations (i.e. Fingerprints) to floor plans should be conducted only for floor plans existing on the server.

Position of the location (i.e. Fingerprint) is to be given in pixel-coordinates as shown on the screen shot in Fig. B.3. It is important to note that the point P(0|0) implies upper left of the image.

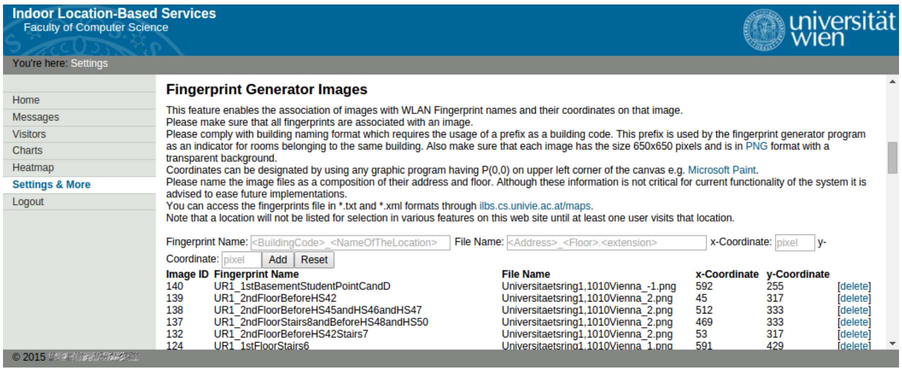

FIGURE B.3: Association of Fingerprints to Floor Plans.

If a location is not associated to a floor plan a default floor plan with default coordinates will be automatically associated to the location before the Fingerprint is published.

C Surveys

Surveys have been conducted through the online services offered by the company SurveyMonkey Europe which complies with European personal data export requirements.

The survey for evaluation of the "IndoorLBS Android Application" consists of three single-choice questions and one text question allowing users to reflect their personal feedback regarding the application. The target group for this survey are currently enrolled students at the University of Vienna representing the actor "LBS User" of the LBS System proposed in this study.

The first question assesses the level of user friendliness of the application, while the third question is utilized to indicate the level of satisfaction of the user in terms of Net Promoter Score introduced in Reichheld (2003). The second question allows the survey participant to reflect his/her perception on usefulness of the four location-based services provided by the mobile application. The fourth question allows the survey participant to provide further comments on areas which were not covered by the first three questions.

This survey has been published on Facebook (`http://facebook.com`) through the web link `https://www.surveymonkey.com/r/JZ9RDNJ`. The link has been posted in eight study groups that were created and are administered the by Computer Science students at the University of Vienna. Eight of the potential participants have received the link as instant message, from which two participants were designated as not eligible due to having completed their studies and thus being not a currently enrolled student at the university. The web link is also published on this study's project website (`http://ilbs.cs.univie.ac.at/index.php?page=app`).

The survey for the evaluation of "Indoor Location-based Services at University of Vienna" consists of three single-choice questions and one text question allowing users to reflect their personal feedback regarding the services. The target group for this survey are lecturers at the University of Vienna representing the "Content Provider" and "Research and Development" actors of the LBS System proposed in this study. The number of questions and the content of this survey is designed in a similar fashion to the survey "IndoorLBS Android Application" except that the first and second questions concern the website and the supported services available to lecturers only.

The survey can be reached by lecturers on this study's project website after logging in (`http://ilbs.cs.univie.ac.at/index.php?page=login`). This survey has been conducted by lecturers at the Worflow Systems and Technology department.

Following pages contain both surveys conducted for the evaluation of this project.

IndoorLBS Android Application

Survey on the website ilbs.cs.univie.ac.at

1. How user-friendly is the application's graphical interface?

- ◯ Extremely user-friendly
- ◯ Very user-friendly
- ◯ Moderately user-friendly
- ◯ Slightly user-friendly
- ◯ Not at all user-friendly

2. How useful are the application's features to you?

	Not at all useful	Not so useful	Somewhat useful	Very useful	Extremely useful
Friends (Location Sharing)	◯	◯	◯	◯	◯
Location (Navigation Assistance)	◯	◯	◯	◯	◯
Messages (Spatio-temporal Notification)	◯	◯	◯	◯	◯
Registration (Automated Attendance Tracking)	◯	◯	◯	◯	◯

3. How likely is it that you would recommend this application to a friend or colleague?

Not at all likely / Extremely likely

0	1	2	3	4	5	6	7	8	9	10

4. I would appreciate your comments on this application.

Done

Powered by

SurveyMonkey®

See how easy it is to create a survey.

Indoor Location-based Services at University of Vienna

Survey on the website ilbs.cs.univie.ac.at

1. How easy is it to understand the information on this website?

- ◯ Extremely easy
- ◯ Very easy
- ◯ Somewhat easy
- ◯ Not so easy
- ◯ Not at all easy

2. How useful are this website's features to you?

	Not at all useful	Not so useful	Somewhat useful	Very useful	Extremely useful
Messages (Spatio-temporal Notification)	◯	◯	◯	◯	◯
Visitors (Automated Attendance Tracker)	◯	◯	◯	◯	◯
Charts (Analytics on Infrastructure Usage)	◯	◯	◯	◯	◯
Heatmap (Analytics on Visitor Interaction)	◯	◯	◯	◯	◯

3. How likely is it that you would recommend this service to a friend or colleague?

Not at all likely — Extremely likely

0	1	2	3	4	5	6	7	8	9	10

4. I would appreciate your comments on this service.

Done

Powered by

SurveyMonkey®

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D Survey Results

The company SurveyMonkey Europe provides basic analysis features for the surveys conducted through its online services.

For the survey "IndoorLBS Android Application" a complete anonymity of participants could be provided as this survey was filled by users on their term regarding location and time of participation at the survey.

A similar anonymity of participants could not be provided for the survey "Indoor Location-based Services at University of Vienna" by "Analyze Results" due to the small number of participants and the fact that each participant filled the survey right after the personal interview/presentation of the website.

Following pages contain analysis of the survey "IndoorLBS Android Application" and "Indoor Location-based Services at University of Vienna" by "Analyze Results" feature of SurveyMonkey Europe.

My Surveys Examples ■ Survey Services

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IndoorLBS Android Application

Summary | Design Survey | Collect Responses | Analyze Results

CURRENT VIEW ?

+ FILTER | + COMPARE | + SHOW

No rules applied ?

Rules allow you to **FILTER**, **COMPARE** and **SHOW** results to see trends and patterns. Learn more »

BENCHMARKS ?

E **SurveyMonkey Global Benchmark**

Professional Services

Consumer Products

SAVED VIEWS (1) ?

E **Original View** (No rules applied)

+ Save as...

EXPORTS ?

SHARED DATA ?

No shared data

Sharing allows you to share your survey results with others. You can share all data, a saved view, or a single question summary. Learn more »

Share All

RESPONDENTS: 17 of 17 Export All Share All

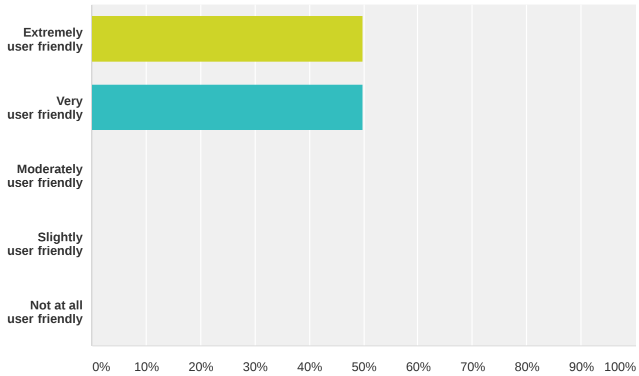
Ü Question Summaries t Data Trends U Individual Responses

PAGE 1: Survey on the website ilbs.cs.univie.ac.at

Q1 Customize Export

How user friendly is the application's graphical interface?

Answered: 16 Skipped: 1

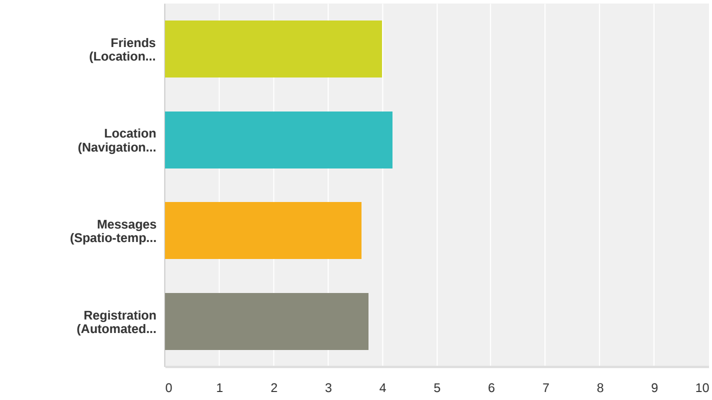


Answer Choices –	Responses –	
– **Extremely user friendly**	**50.00%**	8
– **Very user friendly**	**50.00%**	8
– **Moderately user friendly**	**0.00%**	0
– **Slightly user friendly**	**0.00%**	0
– **Not at all user friendly**	**0.00%**	0
Total		16

Q2 Customize Export

How useful are the application's features to you?

Answered: 17 Skipped: 0

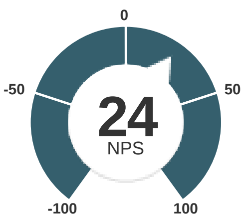


	Not at all useful	Not so useful	Somewhat useful	Very useful	Extremely useful	Total	Weighted Average
Friends (Location Sharing)	0.00% 0	5.88% 1	23.53% 4	35.29% 6	35.29% 6	17	4.00
Location (Navigation Assistance)	0.00% 0	6.25% 1	18.75% 3	25.00% 4	50.00% 8	16	4.19
Messages (Spatio-temporal Notification)	0.00% 0	18.75% 3	18.75% 3	43.75% 7	18.75% 3	16	3.63
Registration (Automated Attendance Tracking)	0.00% 0	6.25% 1	31.25% 5	43.75% 7	18.75% 3	16	3.75

Q3 Hide Benchmark Chart Type

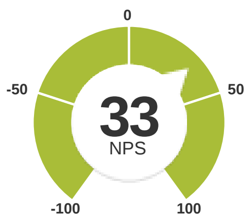
How likely is it that you would recommend this application to a friend or colleague?

Your Net Promoter® Score



Answered: 17 Skipped: 0

SurveyMonkey Global Benchmark



Average from 76,147 Organizations
4/1/2015 - 3/31/2016

Your score is in the bottom 25-50%

Minimum	Lower Quartile	Median	Upper Quartile	Maximum
-100	2.8	40	67.6	100

Your Net Promoter® Score: 24

Distribution of Responses

	Detractors (0-6)	Passives (7-8)	Promoters (9-10)
Your Responses	17.65% 3	41.18% 7	41.18% 7
SurveyMonkey Global Benchmark	20.52%	26.04%	53.45%

Q4 Export

I would appreciate your comments on this application.

Answered: 6 Skipped: 11

Responses (6) Text Analysis My Categories

Categorize as... Filter by Category Search responses

Showing **6** responses

add a friend --> would be better to search a friend by name either, because do you know the matriculation number of your friends? maybe you should offer the possibility to change the language of the interface in other languages.
4/23/2016 8:26 AM View respondent's answers

I think it's a great and creative idea!
4/22/2016 10:47 PM View respondent's answers

Great design and graphics, a simple and user-friendly application!
4/22/2016 5:29 PM View respondent's answers

Automated attendance Tracking is a nice idea, but I worry about data Security and data abuse
4/22/2016 12:57 PM View respondent's answers

really nice. Keep on working.
4/22/2016 12:07 PM View respondent's answers

It's a nice idea, but I would rather use other messengers to communicate with my friends :)
4/20/2016 10:15 AM View respondent's answers

My Surveys Examples ■ Survey Services

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Indoor Location based Services at …

Summary | Design Survey | Collect Responses | Analyze Results

CURRENT VIEW ?

+ FILTER | + COMPARE | + SHOW

No rules applied ?

Rules allow you to **FILTER**, **COMPARE** and **SHOW** results to see trends and patterns. Learn more »

BENCHMARKS ?

E **SurveyMonkey Global Benchmark**

Professional Services

Consumer Products

SAVED VIEWS (1) ?

E **Original View** (No rules applied)

+ Save as...

EXPORTS ?

SHARED DATA ?

No shared data

Sharing allows you to share your survey results with others. You can share all data, a saved view, or a single question summary. Learn more »

Share All

RESPONDENTS: 3 of 3 Export All Share All

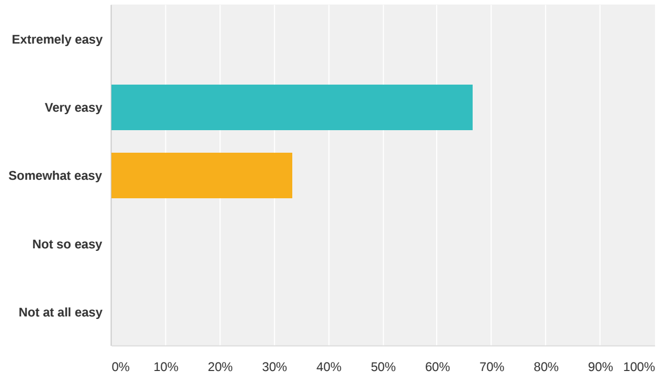
Ü Question Summaries t Data Trends U Individual Responses

PAGE 1: Survey on the website ilbs.cs.univie.ac.at

Q1 Show Benchmark | Customize | Export

How easy is it to understand the information on this website?

Answered: 3 Skipped: 0

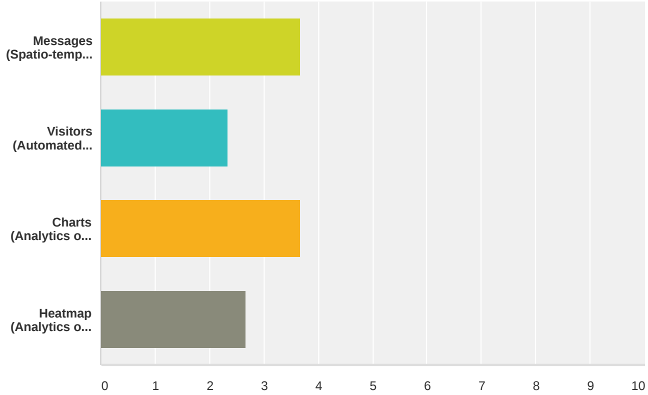


Answer Choices	Responses	
Extremely easy	0.00%	0
Very easy	66.67%	2
Somewhat easy	33.33%	1
Not so easy	0.00%	0
Not at all easy	0.00%	0
Total		3

Q2 Customize | Export

How useful are this website's features to you?

Answered: 3 Skipped: 0



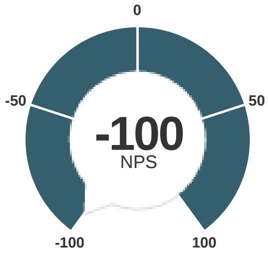
	Not at all useful	Not so useful	Somewhat useful	Very useful	Extremely useful	Total	Weighted Average
Messages (Spatio-temporal Notification)	0.00% 0	0.00% 0	33.33% 1	66.67% 2	0.00% 0	3	3.67
Visitors (Automated Attendance Tracker)	0.00% 0	66.67% 2	33.33% 1	0.00% 0	0.00% 0	3	2.33
Charts (Analytics on Infrastructure Usage)	0.00% 0	0.00% 0	33.33% 1	66.67% 2	0.00% 0	3	3.67
Heatmap (Analytics on Visitor Interaction)	0.00% 0	33.33% 1	66.67% 2	0.00% 0	0.00% 0	3	2.67

Q3

Show Benchmark | Customize | Export

How likely is it that you would recommend this service to a friend or colleague?

Answered: 3 Skipped: 0



Detractors (0-6)	Passives (7-8)	Promoters (9-10)	Net Promoter® Score
100% 3	0 0	0 0	-100

Q4

Export

I would appreciate your comments on this service.

Answered: 3 Skipped: 0

Responses (3) | Text Analysis | My Categories

Showing **3** responses

Heatmaps eher basierend auf den Karten darstellen. Daher z.B. die Raeume einfaerben entsprechend in den verwendeten Karten. Zoomfunktion bei den Karten um diese vergroessern zu koennen.
4/22/2016 5:54 PM View respondent's answers

From a data collection point of view, I think this app is very interesting, but as a user I would not feel too well that all my spatial information (when I have been where) are being collected and analyzed.
4/22/2016 2:31 PM View respondent's answers

Connection to Cewebs and or UFind would be nice. Rename "Message" to "News or Updates"
4/22/2016 9:32 AM View respondent's answers

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