University of Hradec Králové
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MASTER'S THESIS

Radio Fingerprint Acquisition Using Smartwatch

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Study programme: Applied Informatics

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Prohlášení

Prohlašuji, že jsem diplomovou práci vypracoval samostatně a uvedl jsem všechny použité prameny a literaturu.

Declaration

I declare that I have elaborated this thesis independently and listed all the sources and literature.

Hradec Králové day 26th of April 2018 Bc. David Sucharda

Poděkování

Rád bych zde poděkoval Ing. Pavlu Kříži, Ph.D. za odborné vedení práce, podnětné rady a čas, který mi věnoval.

Thanks

I would like to thank to Ing. Pavel Kříž, Ph.D. for professional guidance, incentive advices, and the time he gave me.

Anotace

Název práce: Sběr rádiových fingerprintů pomocí chytrých hodinek

Diplomová práce se zabývá možnostmi sběru rádiových otisků (fingerprintů) za pomoci chytrých hodinek. Tyto otisky se používají k lokalizaci uvnitř budovy. Hlavním cílem této práce je prozkoumat možnosti sběru otisků a návrh aplikace která bude tento sběr umožňovat. V první části práce je potřeba zjistit, jestli je tento sběr na hodinkách vůbec možný. V další části je zpracování aplikace na mobil a hodinky. A jako poslední část této práce je sběr otisků a jejich analýza. Jeden z osobních cílů je zpracovat tuto aplikaci aby byla co nejvíce uživatelky přívětivá.

Annotation

The Master's thesis deals with possibilities of collecting radio fingerprints with the help of smart watches. These prints are used in indoor localization. Main aim of this thesis is to explore possibilities of fingerprint collection and creation of application that will allow it. First part is to figure out if this collection is even possible using smart watch. Next part deals with creation of such application not only for watch but also for the phone. And at the end part there is testing of fingerprint collection and data analysis. One of the personal goal is to make this application as user friendly as possible.

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1 Introduction

As the technology evolves it unlocks more and more possibilities. Just few years back there were no smart watches or phones but at this time they are important part of our lives. As they evolve there is the need for them to have more functions and features. One of them is to locate it's position on the map. This information is very useful since it can prevent people from getting lost, figuring out path to drive, used by military and countless more cases.

Finding out such position is possible using Global Navigation Satellite System (GNSS). Multiple implementations of this system exist such as GPS, GLONASS or Galileo. All of these systems provide location using sufficient number (at least four) of satellites [1, 2]. GNSS solution requires clear line of sight between satellites and the receiving device because signal is not able to pass through buildings. That makes it the main reason why it cannot be used for indoor localization.

There are multiple approaches to find out location inside the building. They can be divided into three main types. First, using wireless signal ranging approach with multiple kinds of data such as Time of Arrival (ToA). Second, using special equipment such as active bats (Ultrasonic). Final, based on Signal Strength Fingerprint Maps (SSFM), in which first part is to collect signal strengths from the environment and construct fingerprint maps. They are then used to match with current signal to obtain the location [3].

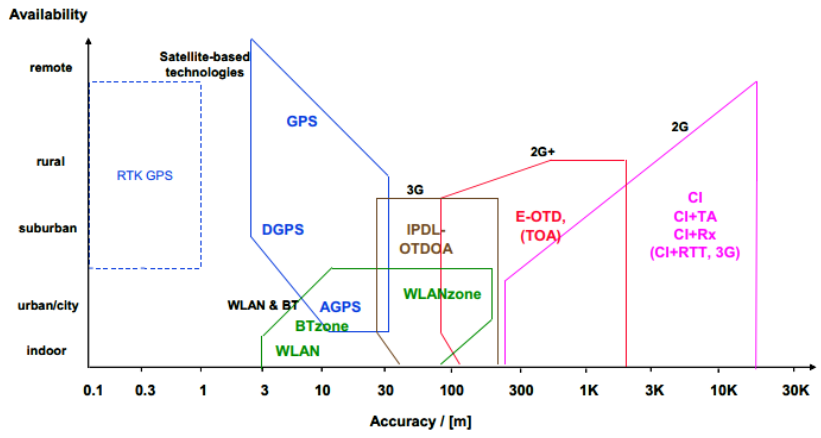

Figure 1.1: Comparison of Positioning Technologies (source: [4])

In addition to these types there are also multiple algorithms used in indoor localization. Some of them are location fingerprinting, triangulation, proximity and dead reckoning [5]. Description of few algorithms can be found in chapter 2.

This thesis is focused on method using radio signal strength (RSS) fingerprinting collecting data from bluetooth, wireless and cellular networks.

1.1 Goals of this thesis

Main goal of this thesis is to explore possibilities of fingerprint acquisition using smartwatch technology. The first question that needs to be answered is if this can be done. Is smartwatch capable of RSS data collection? And the answer to this question is yes since smartwatches have the similar specifications as low-end smartphones.

One of the goals for this thesis is to create an application for Android phone and wear device which handles fingerprint collection. Problem with smartwatches is their diversity in operational system because a lot of watch creators build their own custom systems which can complicate things. Luckily there is new system from Android called Wear 2.0 and it is basically port of Android system to wearable devices.

And final goal is to test created application and figure out if it's data are useful for indoor localization or not.

1.2 Reason for selection of this topic

The reason behind selection of this topic is rather simple. I was introduced to Android during my studies at the University but it was not any deep knowledge so I decided to go for a study abroad to deepen my knowledge. Part of that study was to work for a company where we developed rather technical heavy Android application. It's core part was using multiple APIs but it was focused only on a singe device. So next thing I wanted try was working with multiple kinds of devices and since Android Wear 2.0 is rather new I wanted to test it out. So the main reason is to get more experienced with Android and as a developer.

2 Localization techniques

This chapter describes most common techniques and methods for localization. Most of these approaches have multiple implementations and can be also used in parallel. Fingerprinting for example can be used to increase accuracy of other methods.

2.1 Triangulation

Methods based on Triangulation use geometric properties of triangles to determine target position. This can further be divided into Lateration and Angulation [6]. There are multiple sources of data these methods can use such as distance estimation between device and specific transmitters, measurements of the signal propagation-time (TOA: Time Of Arrival and TDOA: Time Difference of Arrival[7]) and the direction of received signal (AOA: Angle of Arrival[8]) [9].

2.1.1 Lateration

Lateration refers to the technique of determining position based on distance measurements that are calculated using specific devices that know their own position. Mainly used types of Lateration and are Trilateration and Multilateration.

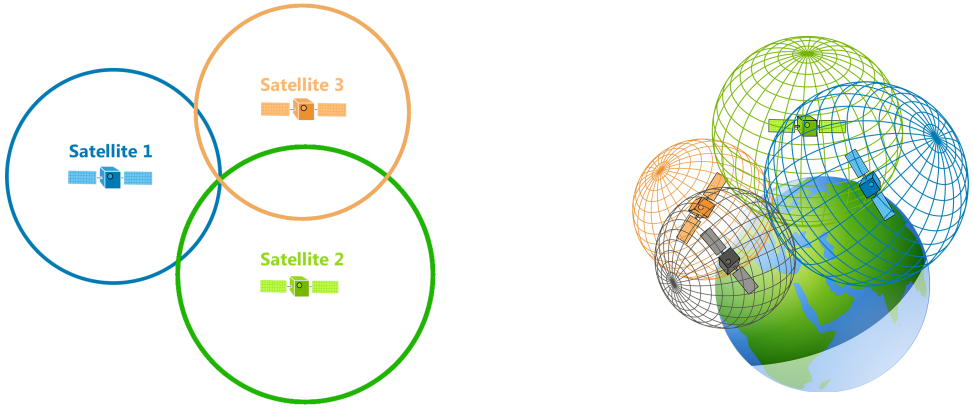

Figure 2.1: 2D and 3D Trilateration (source: [10])

Trilateration uses distance measurements from at least three devices in particular as "tri" in the name suggests [6]. Figure 2.1 illustrates usage of Trilateration in 2D and 3D environment. While working in 2D plane will result with only one specific location point. Moving to the 3D plane can create a problem because signal is send in a sphere which could result in more than one position. That is the reason why some systems use at least four signal sources, example of such system is GPS [2]. Advantage is easy implementation and simple calculations. One down side of this approach is that all devices must have synchronized clock [6].

Multilateration also known as hyperbolic positioning is using Time Difference of Arrival (TDoA) instead of Time Of Arrival (ToA) used in previous case. This approach involves the intersections of hyperbolas rather than circles as shown in Figure 2.2. Main advantage of this method is that only receiving devices must have synchronized clock instead of all [12]. Multilateration was developed for tracking aircraft position and it is widely used.

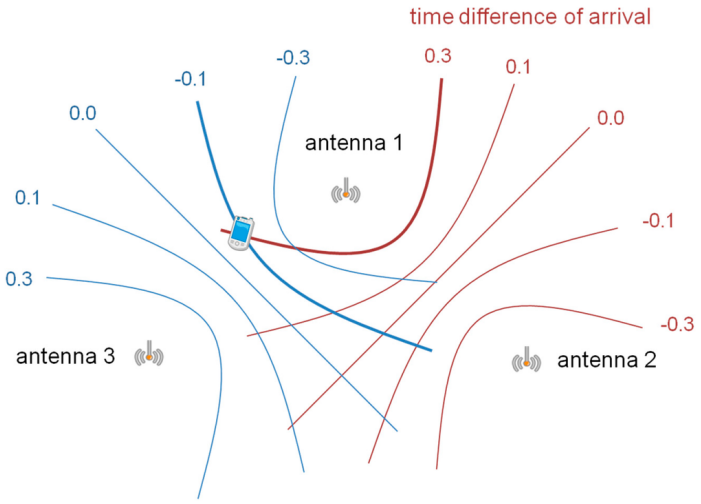

Figure 2.2: Multilateration (source: [11])

Note: At this time term Multilateration is not as strict as it used to be. It can now refer Lateration with more than three devices.

2.1.2 Angulation

This technique uses Angle of Arrival (AoA) of radio signals to determine location. It uses highly directional antennas or antenna arrays. Same as Lateration these antennas are placed in known location and basic AoA requires at least two of them to determine position on 2D plane but more of them can be used to improve accuracy [6]. That makes it an advantage over

Trilateration. Second advantage of this approach is no need for synchronization between devices.

There are few disadvantages of this approach since it needs complex hardware setup due to the use of antennas. Other problem is with multipath locations since it can cause signal reflection making it not useful for indoor localization. And final one to mention is the decrease of accuracy when mobile target moves further from the antennas [13, 14].

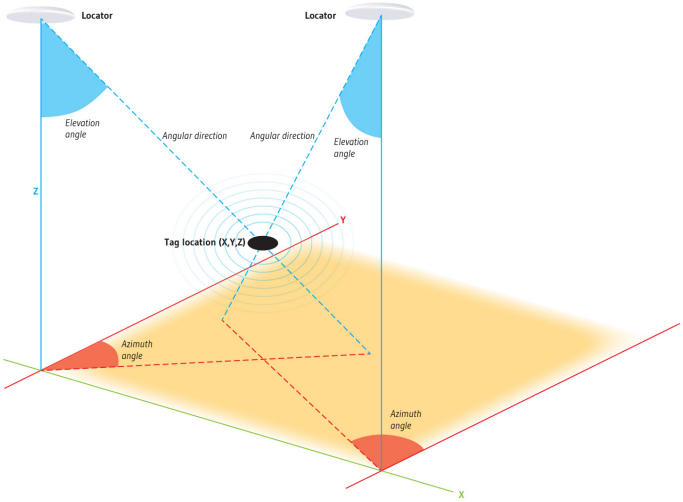

Figure 2.3: 3D location using AoA from Quuppa Intelligent Locating System (source: [15])

2.2 Fingerprinting

This method is a part of Signal Strength Fingerprint Maps (SSFM) type. Main point of this approach is using previously recorded data to figure out device location. Hence fingerprint term in the name. There are multiple kinds of radio signal sources such as bluetooth, wireless or cellular devices that can be recorded.

Fingerprinting has two main phases where the first one is fingerprint maps construction also called offline phase. They are created by collecting Received Signal Strength (RSS) and optional extra features in known locations. All these values are saved in the database and it is called fingerprint map. The second phase is localization itself also known as online phase where the device measures RSS values and compares them with fingerprint maps to approximate position using suitable method [3, 16]. Most used algorithms or methods to approximate position are [9]

- probabilistic methods,
- k-Nearest Neighbors,

- neural networks,
- support vector machine,
- smallest M-vertex polygon.

There are multiple advantages of this approach and the most important is that it does not need any additional or specialized hardware. Next one is no need for time synchronization between the stations. Both of these advantages make it simple and cost effective method for localization. On the other hand building of the map is very time consuming and needs heavy calibration. It is also susceptible to changes in environment such as people presence, object movement or relative humidity [9, 17].

2.3 Proximity

Proximity detection also known as connectivity based positioning calculates only approximate location. Position is determined by cell of origin (CoO) method with known position and limited range [6]. Specific device location is based on cell of the connected device ("associated access" point in Wi-Fi 802.11 systems) as shown in Figure 2.4 [18].

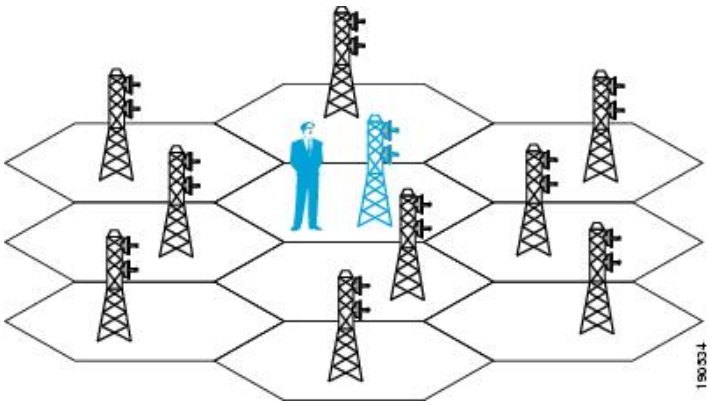

Figure 2.4: Cell of Origin (source: [18])

Primary advantage of this approach is very easy implementation and no need for complicated algorithms and thus making calculations fast. However, for various reasons devices can be associated to cells that are not in close physical proximity. Such errors can happen for example in multi-floor buildings where floor cells overlap. There are additional methods that can be used to improve localization such as using received signal strength indication (RSSI), manual method (human search) or connecting to device with highest signal strength [6, 18].

2.4 Other techniques

Scene analysis is a pattern recognition method that uses features of a scene observed from a particular vantage point to draw conclusions about the location of the observer or of objects in the scene also [19]. This approach has been used in many applications, such as image and speech recognition, as well as location [20]. The advantage is that the location of objects can be inferred using passive observation and features. The disadvantage is that the observer needs to have access to the features of environment against which it will compare its observed scenes [19].

Dead Reckoning refers to a position solution that is obtained by measuring or deducing displacements from a known starting point in accordance with motion of the user [21]. Basically calculate new position based on starting point, travel distance and angle of movement. Because new position calculations are dependent on previous ones there is the need for high accuracy of data since it makes errors cumulative [22].

3 Related Work

Since this is not a novel idea there are some completed solutions and paper written about Fingerprint collection using multiple devices. This chapter will describe few selected solution close to this one for comparison.

3.1 Improving Precision by Using Multiple Wearable Devices

Focused on improving indoor localization using BLE-based fingerprinting with multiple devices [23]. Using combination of smart phone and wear should in this case prevent signal obstruction from human body and at least one of the devices should receive beacon signal. Unfortunately due to low BLE sensibility of wear devices, authors decided to supplement them with smartphone, in this case with Nexus 5 running Android 4.4.

This paper proposes calculating medians using 800 millisecond tests where user can move at most one meter. For all medians at the same position is calculated average and variance, based on which a normal distribution is used to model the potential variation of RSSI. One thing to note is that fingerprint maps are built based on facing direction. There are five main scenarios tested

- P1: device held in hand where body does not obstruct its LOS path to all beacons,
- P2: device is put in breast pocket and LOS may be obstructed to some beacons,
- P3: user holds smartphone in hand and wears a smartwatch on one wrist,
- P4: one device is put in the breast pocket and the other is on one wrist,
- P5: one device is in the breast pocket, and two other devices, each on one wrist.

Firstly, four of these scenarios were tested in a 15x8 meters entrance hall with four deployed beacons in the corners and ten measurement positions. In this location using multiple devices can improve position precision and reduce error by 57%. Table 3.1 shows mean errors

for previously mentioned cases where using more devices improves localization. However there is one position where case P4 will result with higher error then P3 due to building structure and signal obstruction for nearest beacons.

Scenario	Mean error (m)
P1	2.36
P2	1.71
P3	0.96
P4	0.41

Table 3.1: Mean errors at first location (sources: [23])

Secondly, all of previously mentioned scenarios were tested in a conference room with unified ceiling and desks near the walls. This location is used to investigate the impact of beacon density to position precision. Three following combinations of beacons are used

- A: four beacons at the corners,
- B: combination A with one beacon at the center,
- C: combination B with four more beacons at the sides of the room.

Using directional maps at this location resulted in increase of maximum localization error, which was not expected. This error can increase even more when using higher count of beacons and occurs mostly when testing at the edges of the room. Mean error on the other hand shows an improvement, higher with more beacons used.

	Mean error (m)		
Scenario	A	B	C
P1	2.05	2.05	1.76
P2	1.84	1.49	0.90
P3	1.36	1.09	0.63
P4	1.24	0.78	0.23
P5	0.80	0.39	0.07

Table 3.2: Mean errors at second location (sources: [23])

In summary, position error can be improved by three aspects: using more devices, using directional map or increasing the number of beacons. There are two main conclusions of this paper. First, confirmed precision degradation when testing near the edge of the room with obstructed signal from nearest beacon. Second, human body does not greatly change radio signal and device can receive reflected signals with sufficient strength.

3.2 SmartFix

An Indoor Locating Optimization Algorithm for Energy-Constrained Wearable Devices called SmartFix [24]. The main goal of this paper is improve energy consumption efficiency for wearable-based indoor localization using WiFi fingerprints. Single real-time experiment of energy consumption was run and split into two main parts: computation of location and collection of fingerprints. According to this experiment, energy consumption caused by collection is occupies 99% of localization algorithm.

This paper proposes novel indoor localization strategy, SmartFix, that can cooperate with existing indoor localization technologies based on WiFi. It enhances accuracy of such algorithm with a little extra energy cost of calculation but a large save of signal collection energy cost. Aided with machine-learning algorithm, it obtains the relative features given the trajectories of users in certain areas and modify the localization results. SmartFix can save up to 70% of energy while achieving the same localization accuracy when compared to the original fingerprint method.

To test this new system it was implemented with prototypes of TinyLoc [25], MoLoc [26] and basic WiFi fingerprint method using k-neighbor algorithm. TinyLoc is more focused on energy efficiency than location accuracy. In contrast SmartFix analyses the history trajectory of people in given area to improve locating results. It refers to user motion features, SmartFix modifies locating results to achieve satisfying accuracy. MoLoc also leverages user motion by collecting trajectory patterns using device built-in sensors.

All previously mentioned prototypes were deployed with and without SmartFix to test its power consumptions. It only needs single real-time RSS signal in the locating phase to guarantee excellent energy saving performance. Figure 3.1 shows energy consumption of on-time locating on two specific devices: HTC one and Moto 360.

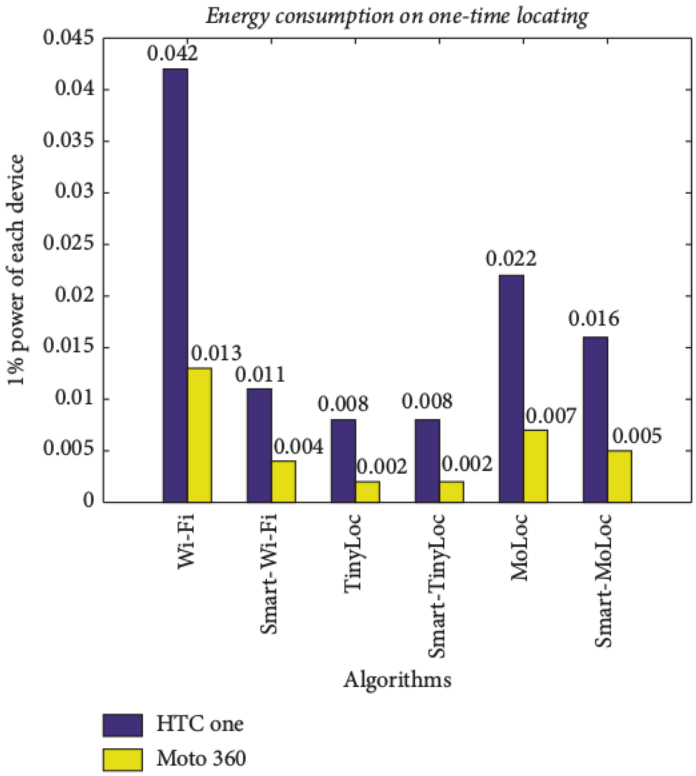

Figure 3.1: Energy consumption based on prototypes (source: [24])

This paper proposed an tested new localization technology, SmartFix, which main focus is to improve energy efficiency for wearable devices. According to experiment, the probability of error within 2 meter can be reached in 80% of cases. Meanwhile, energy consumption is 35% lower than that of MoLoc with the same accuracy, and SmartFix obtains best accuracy with minimal energy cost.

3.3 SmartWatch vs. SmartPhone

A comparative study about localization using smartwatch vs. smartphone [27]. It presents that positioning accuracy using WiFi based fingerprint implemented on a smartwatch is sufficient for at least room-size locations. Average minimum room size is $10m^2$ or at least 3 x $3m$ with maximum of five WiFi APs broadcasting on different channels.

Field study was conducted in six specific locations such as farm, large room, house, two types of medium rooms and one small room. This study collected data using two Android based devices, MotoACTV was used as smartwatch and Samsung Galaxy S3 mini as smartphone. To make fingerprint data more reliable the study collects device orientation (horizontal, vertical) and samples were taken in all four cardinal directions (north, east, south, west).

Test area	Floor size		Fingerprint size		Positioning accuracy SmartWatch (SmartPhone)		
	Dim.	Area	Dim.	Area	5AP	4AP	3AP
Farm	$30 \times 80m$	$2400m^2$	$10 \times 10m$	$100m^2$	82.5%(73.1%)	74.6%(69.8%)	56.2%(51.1%)
Large	$10 \times 20m$	$200m^2$	$2.5 \times 2.5m$	$6.25m^2$	41, 1%(40.3%)	36.9%(33.6%)	27.7%(28.1%)
House	$10 \times 16m$	$160m^2$	$2 \times 2m$	$4m^2$	63.9%(68.5%)	56.5%(66.6%)	47.1%(63.8%)
			$> 2 \times 2m$	$> 4m^2$	83.5%(87.5%)	79.3%(86.6%)	73.2%(81.1%)
Medium	$6 \times 6m$	$36m^2$	$2 \times 2m$	$4m^2$	67.1%(70.1%)	53.5%(67.9%)	35.0%(61.2%)
			$3 \times 3m$	$9m^2$	91.1%(96, 1%)	86.3%(95.2%)	75.7%(93.6%)
Small	$3.5 \times 3.5m$	$12.25m^2$	$1.75 \times 3.5m$	$6.13m^2$	98.1%(100%)	97.2%(99.5%)	91.3%(97.8%)

Figure 3.2: Summary table of results (source: [27])

Figure 4.2 shows summary results of experiments. Most important part of this data is comparison of positioning accuracy between smartwatch and smartphone. In all tests the difference in classification error between the smartphone and smartwatch was at most 5% if data from all five APs is used. On the other hand it can be 25% worse when using small amount of APs in large environments. The result of this study is a confirmation that localization using smartwatch is comparable to smartphone and sometimes even better for home environments. The usage of smartwatches is also preferable since it is tightly connected to a penson.

4 Android

This chapter will provide information about Android and Wear 2.0 technology. Why it was developed and what are the differences between previous version and other wear technologies.

Android is a Linux based operating system for mobile and wear devices developed by Google. The main selling point of this system is that it's open-source project, meaning everyone can access the code and modify it as they wish. Android was mainly developed for mobile phones but in time moved beyond and at this time is implemented into all kinds of wear devices, tablets, televisions and even refrigerators or cameras [47].

4.1 Android system structure

Android is created as a stack, meaning there are functional modules stack on top of each other from Linux core over native libraries to applications as shown in Figure 4.1. Android maintains complete software stacks to enable device creators to run and modify Android for their specific hardware. To support these modifications and testing every release has multiple "code lines" to separate stable versions from experimental work [29].

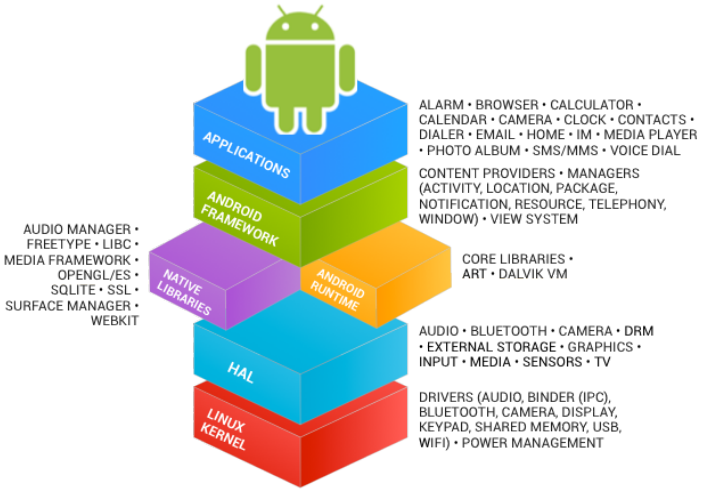

Figure 4.1: Android stack (source: [29])

There are multiple versions of Android system at this time and every single one has it's own version, code name and API level. Version codes are number identifications of a specific system version. Highest levels of these numbers are grouped into code names that are ordered alphabetically. As an example versions 8.0.0 and 8.1.0 have the same code name called Oreo. Finally API level is number identification for compatibility of specific application and it will be compared to API level of device Android system [29, 30].

The highest part of the Android system stack are applications which extend device functionality and are written primarily in Java programming language [34]. These application are packaged into `.apk` file, which is a zip archive, containing all application files like Java classes, layouts, images and more. The most important file is `AndroidManifest.xml` that contains all meta-data about the application, such as permissions, package name, used components, versions and so forth. These application can be shared, for a nominal fee, via official market called Google Play. At the end of 2017 there were over three and a half million applications available in Google Play Store [34, 36, 37].

Android is platform designed to be open source and free which makes it easy to create malicious applications. These application can bypass existing security and steal sensitive data, use telephony services or even gain control over the device [35]. Android has multiple ways to protect against such applications one of the most notable ones are Android Permission Framework and Google Play Protect [34].

4.2 Wear technologies

Interactive wearable, as an example smartwatches, is a new part of mobile computers. Wear devices are categorically different from phones or tables in term of usage, design and user interfaces (UI). According to the app design guidelines by major vendors, users interact with wearable devices frequently throughout daily use. Each interaction is short, often less than 10 seconds, and is dedicated to simple tasks [31].

Important thing to note is that there are multiple kinds of wear devices from smart watches, wristbands, cameras or even glasses [32]. Based on report from Gartner technology research, conducted in 2017, most used wear devices were Bluetooth headset, wristbands and smartwatch [33]. Thanks to their small size wear devices are ideal to use for hands-free communication and health monitoring.

One problem with this diversity is hardware and software compatibility. Every device creator can create their own operating system for specific wear device and it can be difficult

to develop custom applications for it. To avoid such problems this thesis is focused only on smartwatch with Android Wear operating system.

There are three main points to note with watch devices. First, small battery capacity that can be almost ten times smaller then in typical smartphone. Second, point is display with around forty-times less pixels which completely changes properties. Final, scaled down CPU with high efficiency [31]. Last two points are main parts of lowering power consumption of smartwatches but even with these cuts high-end watch devices can have really small battery life only in matter of few days or just hours.

4.2.1 Android Wear

Android Wear is a version of Android OS tailored to small-screen wearable devices. There are not too many changes from system for smartphone but one of the main differences can be seen in UI since system had to be adjusted for watch size [38]. Due to scaled down processing power of watches Android Wear wirelessly offloads data to the smartphone for heavy computing tasks, e.g., voice recognition [39].

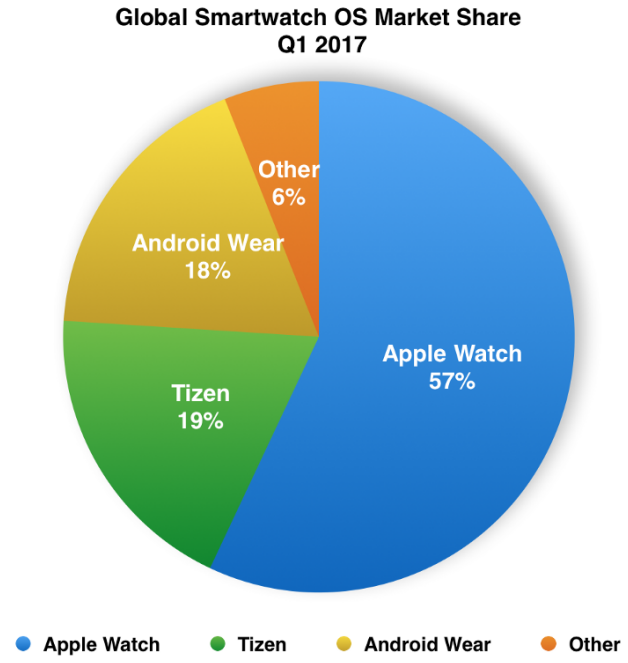

Figure 4.2: Smartwatch OS market share (source: [42])

Android Wear is one of the most popular smartwatch systems but comes with it is own set of problems. Most notable and annoying one is being unable to pair wear with specific mobile device. It can be caused by combination of things such as system compatibility, custom hardware or phone type but it is more common then it should be [40]. Having phone

connected to Android Wear can also cause phone to drain battery way faster. One thing to note is that smartwatch can be connected to only single device and connecting to another requires factory reset. Few other problems can be update issues, notifications not coming through to the watch, not being able to connect to Wi-Fi and system crashes [41].

Even with all these problems it is popular system and in early 2017 it got it's biggest update yet. New version 2.0 brought numerous improvements and features and few of the most notable ones will be described in this section [43–45].

4.2.1.1 Standalone applications

This feature is crucial change and it means that watch applications do not need mobile phone to function. Before this version it was needed to have connected phone with Android Wear support to use applications. Being forced to have Android phone proved as an obstacle for users without one since they could not use any applications on the watch [43, 44].

Since application can now work without phone there should be a way to install them directly. Thankfully part of this update is also standalone Google Play Store where users can browse apps that are designed specifically for the watch [44]. Part of this feature is also enabling watch to use wireless and cellular networks on their own since most standalone applications require this feature. And final part of this update was improving and securing communication with phone. This is now done via Wearable Data Layer API that is used in almost all Google applications and it is also pretty easy to use as a developer [43].

4.2.1.2 UI improvements

Part of new Android Wear version is implementation of Android's Material design guidelines [46]. It has much more "mature" look and darker design for reducing battery drain [44]. It is completely focused on Wear devices and supports both round and square screens with new re-design of application launcher [43].

Figure 4.3: Wear design examples (source: [46])

Android is also trying to catch up with Apple's watchOS and make default watch display, also called watch faces, much more useful. Users can add different widgets of any containing data of any application to the watch faces [43]. This ensures quick access to the data user deems important [45]. All this data displays also match design of currently selected watch face and after clicking it will direct right into the application [44].

Figure 4.4: Wear watch faces (source: [43])

4.2.1.3 Google Assistant

Google Assistant is basically voice controlled smart assistant same as for example Amazon's Alexa, Apple's Siri or Microsoft's Cortana. There are multiple tech sites that run benchmarks of these systems [48–51] and they do not seem to be that different so there is no need to buy one over the other. These systems can pull information that you need or want and they track where you work, sports you like, your schedule, stuff that might interest you and much more [47]. With the update of Wear 2.0 this feature is now available on smartwatches [43, 44].

4.3 Other wear technologies

Tizen, Pebble, Apple, ...

5 Application design and implementation

This chapter describes all important information about created application. First is hardware and software used for developing and testing of the application. Second is structure and description of core parts used in the application.

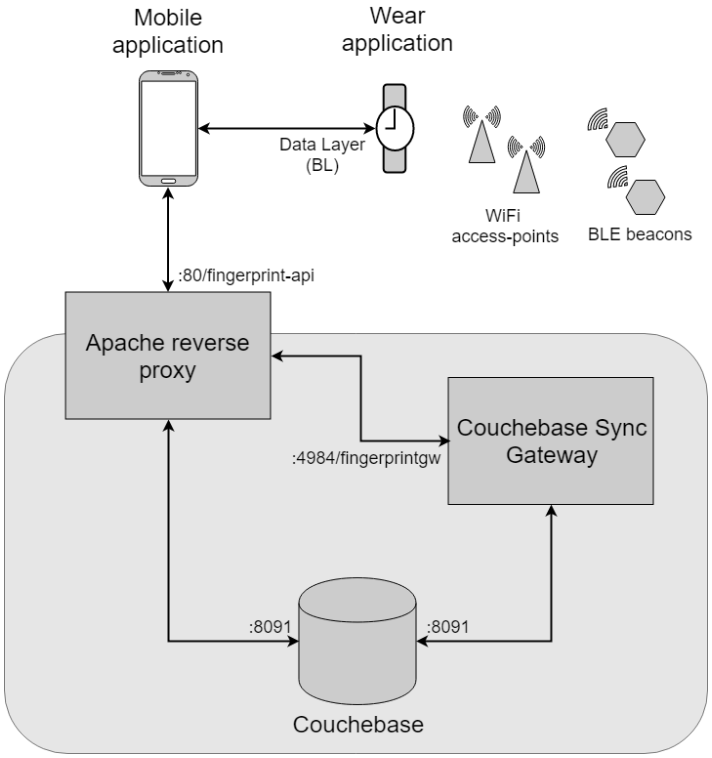

Figure 5.1: Application architecture (based on [9])

Figure 5.1 shows basic devices and technologies used in this application. There are three main part of this implementation, mobile, wear and server application. Mobile and wear parts implement scanning for radio signals and are written in Java language for Android system. Server is also programmed in Java to keep implementations close to each other and make future adjustments easier. Main goal of the server is to store scanned data.

5.1 Hardware

There are multiple hardware devices used in this application. All of them can be seen on ??, where first and the most obvious are smartphone and smartwatch. These devices scan radio signals from WiFi access-points and BLE beacons that are placed in the indoor environment. And a final hardware part is a server holding scanned data from all devices.

5.1.1 Smartphone and Smartwatch

Both smart devices must support scanning of Bluetooth Low Energy beacons that can be done with Bluetooth 4.0 and higher. Secondary requirements are Wi-Fi, GSM and LTE modules to support more data types than just BLE beacons.

5.1.1.1 Phone

Main part of the application is developed and tested on Redmi Note 4 from Chinese company Xiaomi. It is running customized version of Android 6.0 called MIUI. Even thought system was customized, in core it is still Android so there are no problems in that regard [53]. This phone has Bluetooth 4.1 with LE support so main requirement for the hardware is met, with all the secondary requirements also met with Wi-Fi 802.11 a/b/g/n, GSM, and LTE support like most modern smartphones would [52].

One interesting thing about Xioami smartphones is their locked bootloader. It prevents users from any manual updates but most importantly from factory reset. To unlock it owner has to create an account in Xiaomi website and put a request to unlock bootloader. This request is usually processed within two weeks period and there is no actual guarantee of it being approved. After evaluation process is complete user is notified via sms about the result of such request.

5.1.1.2 Smartwatch

First goal of this thesis was to select smartwatches running on Android Wear 2.0 technology. This iteration is quite new currently, which makes it harder to select proper wear device since there are not so many options. During selection process there were around twenty of watches with this system and only five of them were selected to closer inspection based on few articles [54–56].

Only one smartwatch could be selected out of five displayed in Table 5.1. Firstly, wear device had to support BLE and Wi-Fi which all have. Secondly, it must have been sold in

Watch	BLE / Wi-Fi	Czech Republic	Problems
LG W280 Sport	Yes / Yes	No	Battery life is one day or less. Too big in size.
LG W270 Titanium Style	Yes / Yes	Yes	Battery life is one day or less.
Huawei Watch 2	Yes / Yes	Yes	First update can take a long time. Slight Bluetooth pairing issues.
Polar M600	Yes / Yes	Yes	Polar support complains. Phone synchronization issues. GPS location malfunctions.
ASUS ZenWatch 3	Yes / Yes	No	Strap breaks fast. AW 2.0 update can break the watch. ASUS support complains.

Table 5.1: Smartwatch comparison (sources: [57–61])

Czech Republic (CR) since it makes shipping and warranty easier. Only three of five devices were sold in Czech Republic at that time so others were taken out of the consideration. Final decision was made based on extensive research of customer reviews in shopping sites such as Amazon, CZC, Heureka, Alza, wear official websites [57–61] and other tech sites [54–56]. Finally, selected device was Huawei Watch 2 since there were not too many problems in reviews and other requirements were met.

Initial setup of the wear device was composed of two main parts. First, update wear system which took about one to two hours. Second task was to setup the watch and copy Google account, this is where some problem were discovered. Copying of accounts from Redmi Note 4 to the watch never completed. To fix this problem another smartphone (Huawei Y5 II) was used to copy the account, it was already mentioned that only single device can be connected to smartwatch and connecting to a new one requires factory reset removing all the data. It was needed to pair wear with phone without factory reset which was handled via Android Debug Bridge following this [62] article.

Since Google wants to focus also on iOS devices technology Android Wear 2.0 was re-branded to Wear Os by Google to remove confusion in the future [63]. This updated was forced on wear devices, updating it to the newest Android version which forced some changes in the development of this solution. First, implementation bug in scanning library was introduced and had to be fixed. Second and bigger problem was inability to deploy new version of the application from Android Studio to the watch. This, for some reason, effects the main computer used to develop this application and it was fixed by using another computer.

5.1.2 Radio signal devices

As hardware devices are used BLE beacons, WiFi access-points and Cellular towers. Only first two types of these devices can be placed inside a building and are most commonly used in indoor localization. Signal from cellular towers is only a complimentary data that does not have to be used and cannot be influenced since they are placed by telecommunication companies.

5.1.2.1 BLE beacons

Beacons are small devices that can be easily placed in almost any environment. Only thing they do is send an information packets using Bluetooth and nothing else. They are commonly used in museums, airports and as of late in indoor localization [65]. Beacons have their own battery powering them which can last around a year or two without charging because of the new Bluetooth Low Energy (BLE) standard. This technology drastically reduces power consumption and introduces new configuration options regarding the advertising interval and the transmitter output power [64]. More in depth description of this technology and devices was written by Pavel Kriz et al. [9].

There are multiple beacon manufacturers with their own quality, signal strength, battery life and other hardware differences. Changes can also be found in software (packet) specifications for beacons, meaning data they send have different format but it does not mean other systems cannot see them. Usually some software changes have to be made to detect such beacons but they are documented and not hard to make. Beacons are also usually platform independent, making them work with multiple platforms such as Android or iOS [64, 65]. Beacons used in this thesis are from a company called Estimote and they are most commonly used.

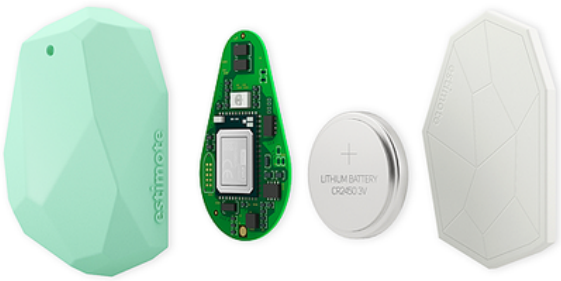

Figure 5.2: Parts of Estimote beacon (source: [66])

Another important thing to note, Beacons are not connected to the Internet and do not collect any data from devices around them. Meaning all the data have to be processed in another device, most commonly a smartphone, and it also makes Beacon safe to use because there is no need to worry about sensitive data theft [65].

5.1.2.2 WiFi access-points

WiFi signals are commonly used in indoor localization due to their presence almost anywhere. In this case several WiFi transmitters of the `eduroam` network made by Cisco were used. They are permanently deployed on every floor of a test building and cannot be influenced or changed.

5.2 Server

Implemented application do not necessarily need a server for its core functionality but it is common and faster to run an analysis of the data and other heavy computational work on a different, faster device. Functionality of the server is to serve as a backup of the data and also as a synchronization point to enable other devices to download fingerprints and upload new ones.

The server infrastructure was built in previous years [9] but it was improved for this solution. It uses NoSQL database to save fingerprints. This type of database does not have fixed scheme, making it easy to save all kinds of data. There are many NoSQL databases, around 250 at this time, to choose from. Selected database is called Couchbase, it saves data in JSON files with its own query language similar to SQL. Part of this database can also replicate data between other devices which could be used in the application part. In the end it was deemed too slow and data heavy for usage in the application, creating the need for creation of a middleman API between Android application and Couchbase database.

As ?? shows server has three main parts to work with. First, already mentioned is Couchbase database to keep scanned data. Second, sync gateway that can synchronize data between devices, not used in this implementation. Both of these part were already implemented in previous years [9]. Final part is web application working as a REST API to send data between the server and mobile application.

This API is written in Java based framework called Spring to keep the code similar to Android. It was documented using Swagger and it handles two main HTTP routes: `fingerprints` and `fingerprints-meta`. Before any tasks are issued, mobile application checks data on

the server using `fingerprints-meta` route which returns count of new fingerprints and last time specific device saved fingerprints on the server. With this information the application knows how many fingerprints to upload and download, in this specific order, to ensure data is stored first. To prevent device memory exhaustion and connection timeout both of these tasks have specific limits, download can process 100 of fingerprints while upload only 20. Server can also generate data files for analysis, split by technology, time, origin device and other filters. To simplify this generation it is similar loading all fingerprints, meaning it does not create file but prints the data directly into the connection stream.

One last thing to note in ?? is the connection with sync gateway. Even though it is not used in this implementation for synchronization it is used to save fingerprints into the database. When data is saved into Couchbase directly sync gateway will not display them, that is why the upload must go through the gateway. This is to ensure all previous and next solution can use this feature without loosing any important data.

5.3 Application Software

Software part for smartphone and smartwatch uses Android system which was already described in Chapter 3. This section will provide basic information about libraries, technologies and systems used in such applications.

5.3.1 AltBeacon Library

Since Android core does not allow scanning for BLE beacons this feature must be implemented in a library extending system features. There are multiple solutions that can be used to scan for beacons such as Estimote SDK [67] which was already used in previous thesis [68]. To change things up BLE beacons are found via AltBeacon Library [69].

Since there was no open and inter-operable specification for proximity beacons, Radius Networks has created the AltBeacon specification as a proposal to solve this issue. It is an open and free specification for BLE beacons with focus to create an open, competitive market for implementation of these devices [70]. Basic configuration of this library can scan for beacons based on this standard and it also supports Eddystone beacons which is Google's open source format. To support already mentioned Estimote beacons this library configuration must be altered to support their detection. Luckily this function can be easily modified to support different kinds of beacons by just one following line of code [69, 71].

```
beaconManager.getBeaconParsers().add(
```

```
new BeaconParser().setBeaconLayout("m:2-3=0215,i:4-19,
    i:20-21,i:22-23,p:24-24"));
```

Code example 5.1: Code to enable all beacon types

This library uses publish-subscribe design pattern, meaning one scan data is send to multiple clients if they listen for them. Using this approach has an advantage of eliminating the need to run a scan per client. Update to Android 8 introduced a bug in this feature making it unable to confirm the registration of client so the scanner has to be reworked thus postponing the data collection and analysis.

5.3.2 Database

This solution makes use of two different types of databases to store all the Fingerprint data for calculations. First, is SQLite database implemented in Android mobile application to save Fingerprints from smartphone and smartwatch. This database is default implementation and most commonly used in Android applications. Second database type is Couchbase implemented on the server `beacons.uhk.cz` to keep all Fingerprint data in one place and this enable synchronization and data analysis.

5.3.2.1 SQLite database

SQL (Structured Query Language) is a standard language for storing, manipulating and retrieving data in databases. It is a type of Relational Database, meaning all data is saved into tables with specified rows and columns [77]. These tables usually have set amount of rows with specific names that protect from adding wrong data, for example you cannot add data `Person(name, surname, eye color)` into table `Person(name, surname)` because there is no column named `eye color` in the table.

Structured data is one of the advantages of this database type and it makes calculation faster but usually uses more storage space. Other advantage is that data can be only saved once since they can be connected to each other. It supports complex queries for creating, reading, updating and removing data (CRUD) and better security with user and table management. Some disadvantages of this system can be with complexity and inflexibility of database scheme because it is hard to setup and does not allow other data then is defined in the tables [76]. Altering schemes in the future can be really complex since there is the need to parse all previous data to the new tables which does not need to have the same scheme as previous ones.

Since SQL with all its features can consume a lot of hardware resources for a smartphone, Android decided to implement lite version of this database. SQLite has the following noticeable features: self-contained, serverless, zero-configuration, transactional [77].

- Serverless = does not need second process for the server.
- Self-Contained = requires minimal support from operating system.
- Zero-configuration = no need for installation or any configuration.
- Transactional = data are protected against failed changes (application crashes, power failure, ...).

5.3.2.2 Couchbase database

Since SQL based databases can be complex to implement, scale and usually require more data storage space there was a motivation to create so called NoSQL databases. Their most important and significant feature is not having a fixed scheme, that makes them easy to scale and replicate between multiple devices. There are around 225 NoSQL databases at this time and selected Couchbase is one of them [73].

Couchbase is distributed, document-based database with its own querying language called N1QL. It is a database focused on simple server configuration and easy usage for clients, with built in caching layer and distribution system it does not require any changes in the application. There can be either one server instance of Couchbase or multiple connected to create a database cluster which holds all the data in multiple locations (nodes) [74]. This data is saved in JSON file format and usually in readable form without any encryption.

```
[
   { "id":"1", "name":"Joe", "lastName":"Doe", "address":{} },
   { "id":"2", "name":"James", "lastName":"Named", "address":{} }
]
```

Code example 5.2: JSON format example

Since SQL is used for decades and it became standard for working with data in databases, Couchbase embraces this approach and extends it for JSON files, this language is called N1QL. It has all the main features of the SQL with some minor improvements [75]. Currently this language can be used only on the server implementation, meaning Android cannot use this feature. Version for mobile application is called Lite and instead of N1QL so called

`views` are used, they are objects containing all the selected data from the documents. Major problem of `views` is being very data heavy which is shown in Comparison section. That is one of two main points why mobile and wear applications use an SQLite instead of Couchbase. Second point is to differentiate between previous solutions and test data consumption and load speed of SQL database.

5.3.2.3 Comparison

Both of these database solutions were tested on Android mobile application to figure out which one is faster and takes less data storage space. As a test 315 fingerprint documents will be loaded and displayed, all of them have more than 500 sub-documents which makes about 150 000 documents. As Table 5.2 shows SQLite takes less space and is almost three times faster in loading all the documents, that is why it was selected for this project. If Couchbase Lite would have faster query time or supported the use of N1QL it would be preferable solution but it is not at this time.

Database type	Data size	Loading speed (315 documents)
SQLite	15MB	23 second
Couchbase without views	31MB	65 seconds
Couchbase with views	91MB	65 seconds

Table 5.2: Couchbase vs SQLite (sources: [57–61])

Selecting SQL comes with a disadvantage since it does not provide any data synchronization, due to that there must be custom solution created which was already described in Server section.

5.3.3 TileView

There are multiple ways to display image map in Android, default solutions usually load the whole picture at once. This works for smaller pictures but it does not have to work for bigger ones because the device can run out of memory. To solve this problem it is usually better to try custom library or widget created specifically for displaying such images. One approach is to use 2D or 3D library to display image, these libraries usually work with the image as a whole and implement complex functionality to display it without memory exhaustion. The other approach, also used by Google Maps, is to cut the big image to smaller

parts (`tiles`) and display them next to each other. It also makes creating of zoom levels easier for two reasons.

- Every zoom level has a collection of images, this makes it easy to keep a good quality for zoom since images are not stretched on the screen as single one would be to maintain the same level of zoom.
- When zoomed pictures out of the screen do not have to be kept in memory, this cannot be one with single picture.

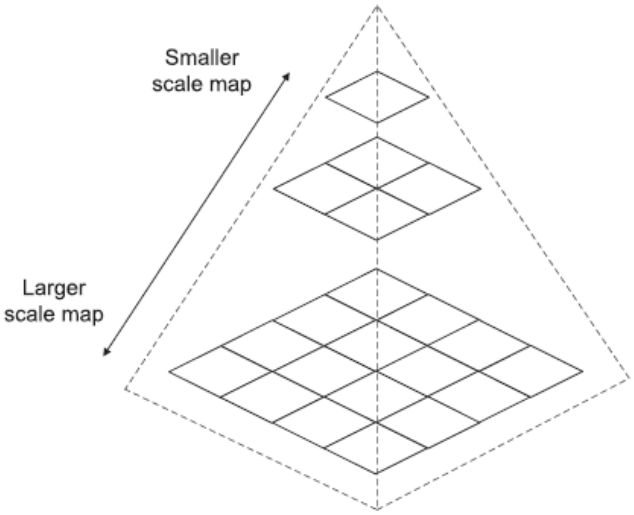

Figure 5.3: Tile pyramid for zoom levels (source: [78])

5.4 Application implementation

Implementation of this application is split into two parts, mobile and wear. Both of them have to implement two tasks in order to be able to create fingerprint maps. First, scanner for radio signals which will record Bluetooth Low Energy beacons, WiFi access-points and Cellular towers. Second, communication between both implementation, mobile and wear, to allow sending fingerprint information between them. Those are two core functions for both applications but since the synchronization server is used, mobile part also has to communicate with the server.

Both of these applications are programmed in Java language using Android Studio, each of them has a separate configuration and is aimed to different system versions.

5.4.1 Scanner

Scans for radio signal and creates a fingerprint with specific position, device and selected sensor information. This additional data, especially about the device, will help with analysis by splitting data into groups.

There are multiple parts to this task and most of them are very computational heavy so it is better to implement it in a separate `Thread` to prevent application from freezing. Android provides multiple solutions for running tasks in separate Threads.

- AsyncTask - Simple solution mainly focused on short running tasks. This implementation is easily created since it handles basic functions like running task, run code before and after task, publish progress to the main Thread and many more.
- Service - Mainly focused on long running tasks and it is run immediately after it is started.
- Custom Thread - One of the hardest solutions because developer has to handle all the task related to Threads life-cycle and be careful to prevent creation of multiple unwanted Threads.
- JobScheduler - One of the newest implementations, it is focused to schedule task and run them when the device has required resources ready and not immediately.

Scanner is run using JobScheduler, it is a new technology and Android wants to develop this feature. Handling scanned data is implemented using publish-subscribe design pattern handled by `BroadcastReceiver`. There are three separate Receivers for each type of signal collected and one more for collecting data from sensors.

5.4.1.1 JobScheduler

This feature was introduced in Android 5.0 and it remains under active development with major changes in Android version 7.0. This platform collects information about jobs that need to run across all the applications. Some information collected about specific jobs are: required network access, is the job periodic, should the job be scheduled after device restart and more. This information is used to schedule jobs to run at, or around, the time they were scheduled. JobScheduler is intelligent about running jobs and it uses so called batching, which is combining multiple jobs to reduce battery consumption [30, 79].

```
// Building job to run
```

```
JobInfo.Builder jobBuilder = new
   JobInfo.Builder(FingerprintScanner.JOB_ID, new
   ComponentName(getPackageName(),
   FingerprintScanner.class.getName()));
jobBuilder.setOverrideDeadline(1000);
jobBuilder.setPersisted(false);
jobBuilder.setExtras(bundle);
// Run created job
JobScheduler jobScheduler = (JobScheduler) getSystemService(
   Context.JOB_SCHEDULER_SERVICE );
jobScheduler.schedule(jobBuilder.build());
```

Code example 5.3: Schedule Firngerprint scanner job.

This code is used to schedule Fingerprint scanner. Firstly, a job has to be created with specific ID and class to contain job code. Secondly, job information are provided: this task should start around a second after scheduling, it is not run after device restart and there are custom data send to it via `setExtras()` function. Finally, job scheduler is loaded and this job is run. One thing to remember is to not create a new instance of JobScheduler class since it is a system service.

5.4.1.2 BroadcastReceiver

Broadcast messages are send from Android system and other Android applications, similar to the publish-subscribe design pattern. This messages are send when an event occurs such as system boot up, start of device charging or network connectivity change. In addition to system events, custom ones can be created in the application to inform other applications. When a broadcast is sent, the system automatically routes it to application that have subscribed to receive that particular type of broadcast [30]. Following code illustrates how easy is to send a custom broadcast identified by specific action, which can be system or custom. BLE beacon data is added to be received and parse into Fingerprint. Last line sends the actual broadcast to be received by other applications.

```
Intent intent = new Intent();
intent.setAction(ACTION_BEACONS_FOUND);
intent.putParcelableArrayListExtra(ACTION_BEACONS_DATA,
   foundBeacons);
```

```
sendBroadcast(intent);
```

Code example 5.4: Send broadcast with BLE beacons found.

Receiving broadcasts in application has two steps. First, register the receiver implementation and specific broadcast message it should receive, this can be done via manifest or dynamically in code. If receiver is registered using manifest, application is launched (if it is not running already) when the broadcast is sent. Second, create an implementation of BroadcastReceiver class that will handle information and data using `onReceive()` function.

There are two BroadcastReceiver used in the Scanner. First, used for WiFi scanning since it is a default Android solution. Second, BLE scanner was modified to use this approach because there are multiple parts of this application that can receive information about found beacons. Other two scanners use Listeners which are interfaces handling communication between system and application.

5.4.2 Device communication

In this application device communication is used to send fingerprint data between devices using Bluetooth. Mobile application sends information about the fingerprints such as location and scan duration, these values are same for both devices. Wear application will in return send result data after scan was finished to save it into the mobile database.

First implementation of this feature was build upon Bluetooth chat example application from Google. This implementation was using three separate Thread to make connection, authorize it and then to send the data when device was connected. Both devices had to accept the connection to send the data, which is normal, but there were some connection loss issues where one devices was considered connected and sending data while the second device was disconnected and not receiving data. That is why this solution was removed at early development stages and substituted by Google's Data Layer API.

To limit data consumption of this application on wear it does not run constantly. Before any scan is started mobile informs wear to start the application, after this is done mobile sends fingerprint data to wear part of the application which is returned after the scan is done with acquired data.

5.4.2.1 Data Layer API

Data Layer is commonly used by Google to send data between their applications. There is an implementation using this feature called Google Tag manager which is sends data from

websites to other Google tools like Analytics or Adwords. In this case is a JavaScript object or variable creating virtual `layer` of website application which contains various `data` points, making its name, `Data Layer` [80].

Since it proved as a useful solution it was also implemented for Android and it is a part of Google Play services. The Data Layer API allows to store and retrieve data from different kinds of devices, it this case between mobile phone and wear. There are multiple ways to send data depending on what should be sent [30].

- Data Item - It provides a data storage that is synchronized between mobile and wearable device. Whenever data changes all devices using this item are then informed about the change and it is identifies by Uri containing creator and path.
- Asset - Used to send binary blobs of data, such as images. It takes care of the data transfer automatically using caching to avoid sending the same data multiple times.
- Message - Good for sending small amounts of data or remote procedure calls, such as controlling mobile media player from wearable. If the device receiving data is connected sender receives a result code confirming successful data send. Although if the device is disconnected right after receiving the result code this information might not be 100% precise.
- Channel - Transfers large data entities, such as music and movie files. It saves the disk space over Data Item or Asset because it does not create copy of the message on local device before synchronization. It can be also used to transfer streamed data, such as music pulled from a network.

This application uses message system and data items, where messages are send to start wear application and confirm its startup and later Fingerprint data are send via data items. Since application may be either in foreground or background there need to be two solutions to receive the data. First, a service that runs when the application is not started or in the background. Second, any activity can implement an interface that will get received data in foreground.

One important thing to note is, to send the data successfully between the devices they must have the same APK signatures, meaning they must be signed by the same key. For example, debug versions of two applications developed on two different computers will not be able to send data due to this restriction.

5.4.3 Server communication

Main task of communicating with the server is to synchronize data on the mobile, downloading previous fingerprints and upload newly scanned ones. This feature uses server api to transfer data and since this is a very data and computational heavy task it is run in a separate thread same as a scanner, also using a JobScheduler. It was already mentioned that server api is documented in Swagger, this tool can also generate android code to communicate with the server based on defined functions in the documentation. This will generate working code without the requirement of using secondary library but the code is unnecessary complex and so this application uses simple library called Retrofit.

Even though the new version of Android Wear OS makes this feature easier to implement on the wear device, it is still used only in the mobile application for one simple reason: to lower power consumption.

5.4.3.1 Retrofit

Retrofit is a library turning HTTP API into a Java interface making the implementation simple. Such interface contains calls with parameters based on the api documentation, that can return either raw response or automatically convert the data into Java classes based on configuration. Creating the interface is only one of two parts to make this library working. Second is create an instance of this library's main class with a configuration specific to the api.

```
public interface ApiConnection {
   @GET("fingerprints")
   Call<List<Fingerprint>> getFingerprints(@Header("deviceId")
      String deviceId,
      @Query("timestamp") long timestamp,
      @Query("limit") int limit,
      @Query("offset") long offset);
}
```

Code example 5.5: Retrofit interface example.

Small example of Retrofit interface class with a function for getting fingerprints. Firstly, Retrofit must be informed which HTTP call it should use, such as GET, POST, PUT or DELETE, part of this information can also be URL path added to the call, `fingerprints` in this case. Secondly, all of the parameters must inform where they should be posted, in header, body

or query.

```
Retrofit retrofit = new Retrofit.Builder()
    .baseUrl("http://beacon.uhk.cz/fingerprint-api/")
    .addConverterFactory(JacksonConverterFactory.create())
    .callbackExecutor(Executors.newSingleThreadExecutor())
    .build();
```

Code example 5.6: Retrofit configuration example.

There is only one required configuration to make retrofit work and that is defining base URL so the library knows where to post the calls. Some other configurations might be adding data converter which converts the data from Json to Java classes, run calls in different threads or create custom HTTP client.

5.4.4 Application screens

Mobile application has three screens, scanning, surrounding devices, synchronization screen and wear application has only one containing information about the scan.

5.4.4.1 Scanning screen

This screen is the core of this application it shows the map of building floor with fingerprint positions as markers. This is implemented using TileView library. Main point of the markers is to create new fingerprints on the same spot and also to display more information about all fingerprints at that spot. Second thing implemented by the markers is to delete last fingerprint group, meaning multiple fingerprints with the same scan identification which can be useful for "broken" or unfit fingerprints. This feature had to be implemented due to issues with WiFi scanning and make to make data more reliable.

6 Testing and data analysis

This chapter goal is to show application testing, data collection and analysis.

6.1 Data collection

6.2 Analysis

7 Conclusion

7.1 Application improvements

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Attachments

1. CD with application
    a) Application data
2. Public Github repository with application and thesis text.
   `https://github.com/Del-S/WearNavigation`

Univerzita Hradec Králové
Fakulta informatiky a managementu
Akademický rok: 2017/2018

Studijní program: Aplikovaná informatika
Forma: Prezenční
Obor/komb.: Aplikovaná informatika (ai2-p)

Podklad pro zadání DIPLOMOVÉ práce studenta

PŘEDKLÁDÁ:	ADRESA	OSOBNÍ ČÍSLO
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TÉMA ČESKY:

Sběr rádiových fingerprintů pomocí chytrých hodinek

TÉMA ANGLICKY:

Radio Fingerprint Acquisition Using a SmartWatch

VEDOUCÍ PRÁCE:

Ing. Pavel Kříž, Ph.D. - KIKM

ZÁSADY PRO VYPRACOVÁNÍ:

Cíl: Navrhnout a implementovat aplikaci pro mobilní telefon a chytré hodinky na platformě Android Wear 2.0, pomocí které bude možné změřit rádiové fingerprinty souběžně pomocí mobilního telefonu a hodinek. Vyhodnotit a porovnat přesnost indoor lokalizace s použitím existujících algoritmů využívajících rádiové fingeprinty.

Osnova:
1. Úvod
2. Indoor lokalizace s pomocí rádiových fingerprintů
3. Platforma Android Wear 2.0
4. Analýza a návrh
5. Implementace
6. Testování, zhodnocení výsledků
7. Závěr

SEZNAM DOPORUČENÉ LITERATURY:

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http://www.mdpi.com/1424-8220/17/8/1789

Podpis studenta: ..... **Datum:** 15. 11. 17

Podpis vedoucího práce: ..... **Datum:** 15.11.17