UNIVERSITY OF GOTHENBURG

Evaluating the usage of Bluetooth Low Energy Beacons and Smartphones for Indoor Positioning Systems

Bachelor of Science Thesis Software Engineering and Management

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Abstract

Due to the extensive adaptation of smartphones outdoor positioning by GPS has become an everyday commodity for many people. When it comes to indoor positioning things are different. Topology constraints in indoor environments are much more complex than those in outdoor environments. Many technologies and techniques have been used to solve this problem and as new technologies arrive these need to be evaluated.

This papers aims to evaluate the Bluetooth Low Energy protocol, the way it works in indoor environments and explore the possibilities of improving the quality of the received signals so they can be used with smartphones.

We conducted tests in a number of different indoor environments in order to identify the key attributes that affect the signals and suggest ways to improve them. To conduct these tests we first built a smartphone application to allow us to make measurements of BLE signals as well as implementing ways to improve them. Data was collected from these tests and used to guide the direction of further improvements.

After evaluating the new Bluetooth sensors, it is still unclear if accurate indoor positioning can be achieved but further insights are shared and guidance for future implementation and research is given.

1 Introduction

Since becoming operational and available to civilians in the mid 1990's the Global Positioning System has become an everyday commodity. It is no wonder we have become accustomed to the luxury of accurate positioning when every smartphone provides us a link to this system. What happens though when positioning and navigation instructions are required indoors? GPS signals cannot overcome and penetrate inside buildings, they rely on Line of Sight (LOS) communication yet our need persists.

Many solutions have been implemented in attempts to meet this need, each with strong sides and weak sides. These solutions are based on a combination of signal communication hardware and algorithms for signal processing and positioning. As GPS positioning was the original it is not surprising to see that attempts have been made to bring GPS positioning indoors, Fluerasu used GNSS transmitters in a repeater style setup to spread GPS signals indoors[5]. Technologies that are more commonly seen in indoor usage that have been used for indoor positioning are for example Bluetooth used by Subhan[17] and WiFi used by Jaffre[9]. Some less frequent technologies include RFID[6], NFC[10] as well as hybrid solutions[2]. There are also proprietary technologies that employ their own signal structure such as the Locata system.[16]

Together with the communication hardware a positioning system also needs some way to translate a signal into a location. These techniques can be roughly sorted into three categories: proximity, geometric and scene analysis[11]. Proximity methods create zones and assigns the users location when they enter that zone[11]. Geometric methods make use of signal measurements from reference points and use them as the input to solve geometric equations[11]. Scene analysis methods create what is called a fingerprint from multiple signals measured at one point and try to find a location by matching the fingerprint to a database of reference fingerprints[11]. The hardware and algorithms are connected by the signal which is the output of the hardware and the input of the software. These systems rely on the quality of the signal yet there are many things that affect the signal, such as the layout of the room, and modeling the propagation of a signal indoors is no easy task due to the high risk of multipath issues[11].

While there has been much work done on this problem it remains a relevant topic, especially as new technologies appear which may address the problem in an improved way.

One such technology is Bluetooth Low Energy (also known as Bluetooth 4 and Bluetooth Smart). BLE was developed to address the energy issues of past Bluetooth versions, at the same time it offers other benefits. BLE was designed to be used with Smart devices for context based applications. BLE provides ubiquitous tiny transmitters, broadcasting at short range that do not need to be networked. Bluetooth also has the benefit of being a widely adopted technology with many of the major smartphone manufacturers already having support for BLE. With the popularity of the smartphone this sets BLE in a good position for being a general solution where much hardware is already in place.

The aim of this paper is to evaluate this new technology and offer an understanding of what techniques can be used to build a positioning system around BLE beacons and smartphones.

Research questions

- Is BLE a suitable choice for indoor positioning systems using smartphones?
- How can the quality of BLE signals be improved?
- What software techniques are viable to use with BLE and smartphones?

By answering these questions we hope to allow developers to create indoor positioning solutions using BLE by giving them a better understanding of the indoor positioning area and BLE's role in that space. In the following chapters we will give a broader background on technologies used but more importantly the techniques available. Then we will proceed to describe how this study was carried out before presenting our results. We will then discuss our findings before wrapping up with the conclusions.

2 Background

As we've mentioned indoor positioning systems cannot rely on GPS signals as the signals do not penetrate buildings. Thus other techniques have been developed to provide positioning information indoors. Most methods proposed for indoor positioning are based on radio signal technology.

Many different technologies have been employed to solve the problem of indoor positioning and we would like to iterate on the examples we mentioned in the introduction, adding only a little more insight into the width of the field and the multitude of application areas. The application areas vary as do the software techniques used with each technology. Subhan used Bluetooth signals together with a trilateration algorithm in a fingerprinting network[17]. Alongside the geometrical methods there are also methods like nearest neighbor and Bayesian probabilistic methods, as exemplified by Jaffre in their paper on how to use Wifi for indoor positioning[9]. Tied to the internet of things is the paper by Hai-Lan where they used RFID technology for finding the positions of items in a warehouse[6]. Another application area is indoor parking management, as shown by Kim, Kim used NFC technology for their system[10].

As GPS positioning was the original it is not surprising to see that attempts have been made to bring GPS positioning indoors; Fluerasu used GNSS transmitters in a repeater style setup to spread GPS signals indoors[5]. Technologies that are more commonly seen in indoor usage that have been used for indoor positioning are for example Bluetooth used by Subhan[17] and WiFi used by Jaffre[9]. Some less frequent technologies include RFID[6], NFC[10] as well as hybrid solutions[2]. There are also proprietary technologies that employ their own signal structure such as the Locata system.[16]

The software techniques used can be categorized in a few other ways than those mentioned in the introduction. One way is by which kind of location they offer such as physical, symbolic, absolute and relative locations[11]. Physical locations are coordinates on a 3D or 2D map for example[11]. Such a map could be derived from a buildings blueprint. Symbolic locations use natural language to for example give the location "in the office"[11]. Absolute and relative locations are connected to the physical locations but denote a difference of how areas are split. In an absolute system all objects share the same reference plane, while in relative system the plane is created by individual base stations[11]. There are also differences in what part of the system is moving. In a remote positioning system the transmitter is mobile and the measuring units are fixed, calculations are done at one of the measuring units[11]. If the measuring unit is mobile and does its own calculations based on fixed transmitters it can be called a self-positioning system[11]. If the result is transmitted to the unit that will use the result both remote and self-positioning systems can be called indirect remote and indirect self-positioning[11].

To go deeper into the classification we presented in the introduction we would like to look further into the geometric and scene analysis techniques, there is not much more to say about the proximity methods.

The geometric methods are split into triangulation and trilateration[11]. Triangulation uses the measured angles to a set of reference points, with known locations, to calculate an intersection of points and therefore relies on directional antennae[11]. Trilateration on the other hand uses a measured distance to a set of reference points, with known locations, and uses the distance as the radius for circles, finding the intersection of these circles (or spheres in a 3D plane) gives the location[11]. These distance measurements can either be taken from the signal strength or from information inside the signal. There are a few variations of using information in the signal but most rely on the time the signal has spent traveling (as such the signal must carry a timestamp), either one way or a return flight (time of arrival and returned time of flight)[11]. The downside of such methods is that all units in such a system must be synchronized in time and due to multipath the time traveled could be longer than the actual distance[11].

Scene analysis methods are often called fingerprinting techniques because they collect fingerprints of a location and use these to find a location[11]. A fingerprint is a collection of signals received at a certain location in the scene, in this way they aim to make the fingerprint location specific, such fingerprints are often based on the RSSI values collected from transmitters in range[11]. Scene analysis is done in two stages. First is the offline stage where a set of reference fingerprints are created and stored together with their coordinates in a database. In the online stage that follows the system creates the same kind of fingerprint for the user's location and then uses an algorithm to find which reference fingerprint it is most similar too to give an estimated location[11]. Scene analysis techniques for finding the location include k-nearest-neighbor, probabilistic methods (treating it as a classification problem) and neural networks[11]. Scene analysis is also affected by the same multipath issues as the geometric methods[11]. While scene analysis require more preparation (training a neural network for example) they can be less computationally complex than geometric methods at run time.

In many ways it is the choice of technology and hardware that decides what options in software are available. As such it is important to understand the tradeoffs in both hardware and software. A hardware may offer advantages in signal quality but offer less options for software solutions just as a software platform may offer less control over the signal quality. As we can see many positioning systems calculate the distance between the user and the location of the beacon based on the RSSI values. Unfortunately the data can have strong variations due to the propagation model[4] used. Especially indoors where there are many aspects of corruption in the environment, such as transmitter position and how the human body absorbs signals[17]. Usually there are large amounts of metal, furniture, reflective surfaces and people which affect the propagation of the signals and cause multipath and other path-loss effects, dead spots and interference. To iterate, modeling the propagation of signals indoors is no easy task[11].

Propagation modeling makes the procedure even more difficult and important when it comes to using the data in techniques like trilateration to accurately calculate the location of the user. Different methods have been used so far in order to filter the data and provide better results. Adapting smoother based location and tracking algorithms for indoor positioning by making a fusion between RSSI and link quality indicator (LQI), which is particularly well suited to support context aware computing. Experimental results showed that the proposed mathematical method can reduce the average error by around 25%, achieving better results than the other existing interference avoidance algorithms[7]. Hybrid approaches, statistical methods and Kalman filtering[15] have also been used in order to separate the value from the noise and remove the statistical error from the values. These algorithms use data observed over time containing variations, noise and other inaccuracies to give a prediction of variables that tend to be more accurate than those based on a single measurement alone. Systems so far manage to achieve a proximity between 0.74m and 0.56m, inside test environments[12]. If we compare with similar systems that use RSSI from wireless signals which usually achieve an accuracy of 2-3m[1].

We have mentioned multipath several times and would like to make a note about what it is. Multipath is the phenomena where a signal travels from a transmitter to a receiver in more than one path. Additional paths may occur if the signal is refracted or reflected by a surface. Having a signal come in from many directions can create errors in the readings, especially if for example the signal waves realign after bouncing and create an amplification effect. The opposite may happen where the signal is weakened by clashing with another. If your system relies on the stability of the signal these are big issues. There are techniques to mitigate the multipath issue([3, 13]) but these require control over how the transmitter and receiver process the signal before turning it into a RSSI. As this paper is dedicated to the use of standard smartphones we will not include these techniques as a developer for a smartphone based system will very rarely have control over the individual hardware modules of their devices.

3 Methodology

Research setting

Within the field of information systems there are two paradigms of research, behavioral research and design science research. While behavioral research seeks to build truth about an existing system(such as understanding the underlying phenomena that explains the usage of the system and try to make predictions), design science aims to explore a problem and build utility. Such a utility can be an artifact which can then be used to evaluate the problem and how the artifact addresses the problem[8].

In our study we made use of the design science paradigm to aid the field of software engineering and applied the build and evaluate model it describes. This was a good way for us to explore the problem to gain an understanding of the problem as we are trying to solve it. Design science goes well with the iterative mindset of Agile, which is often used in software engineering, as it also builds on a loop of build and evaluate.

The key concept of design science is its iterative nature. The results are derived from the cycle of generating design alternatives and testing these alternatives. In this way design science is a search process to find a solution[8].

We carried out these iterations to produce an instantiation, a simple smartphone application that would let us do measurements of RSSI signals from the beacons. Our interest was to evaluate the usage of BLE beacons together with smartphones for possible indoor positioning systems. As such we were limited by the platforms and hardware we used. As an example we did not have direct control of the signal processing, rather we used the Android platforms SDK to do the BLE scanning for us and it returns simply the RSSI together with information such as MAC address of the scanned unit. On the beacon side of things we used beacons developed by Estimote which are very simple beacons that only broadcast their ID and have only two settings, their broadcast signal strength and broadcast interval.

Data collection
After a finished iteration we used the application in our live setting inside the science park that we were collaborating with. In our data collection step we used our app to gather a sample from three different areas (with different characteristics) to evaluate the stability of our signal. Each area had a few different characteristics such as size, the presence of water and obstacles but the zones used remained the same throughout the project. There were three zones used: the cave, the water area and the obstacles area. The cave is a small closed room with sharp edges in order to simulate a large number of reflections. Physically the room looked like a cave. Water is another factor that affect the signals. The water zone tests were done above an area of water. Finally we have included a case where the beacons may not have clear line of sight with the receiving device and this is the obstacles area. During all of tests people were passing by at a random pace. We did not have the opportunity to use the space without any visitors. However, most positioning systems are aimed for an environment with a regular frequency of people, so this is closer to actual field testing.

Data analysis and artifact evaluation
The data for each zone was then examined. The examination was to find a reason for the instability in our signals and to produce possible solutions. Our goal was to stabilize the signal using only software techniques that use only an RSSI as input. Because due to our platform choice we had no direct control of the signal processing unit itself. The examination was carried out through simple observation of the values collected as well as graphing the data. Based on the data we collected we then investigated to make the adjustments we describe in our results.

Threats to validity
First of during our data collection we collected only 50 averages per area, this is perhaps a small sample size as well as not repeating the sampling causes the data we worked with relatively small but enough to work as an indication for future adjustments. We did not make use of any formal statistical analysis which in retrospect was a mistake, even trying to make a tentative evaluation should include formal analysis, for future work we would strive towards defining a signal stability and accuracy index to formally compare how effective each countermeasure implemented is.

Ethical issues
We anticipate no ethical issues to have arisen during this study as very few individuals were involved, no interviews or similar that would require the consent of individuals was performed. We do however perceive the ethical threat that the usage of the result of this study may have. Privacy is a basic human right and the authors are aware that any study into the ability to track and accurately locate a person can be misused and as such urge society as a whole to be wary of how technologies like these are used and that they ensure that any sort of tracking and locating is done solely with their users consent.

4 Results

We've mentioned earlier in this paper that the simple beacons used had only a limited amount of settings, their broadcast signal strength and the interval at which broadcasts were made. Before we get into our results we would like to quickly show how these settings can affect the readings and the system. We will also explain how to interpret the graphs we present.

The signal strength setting is simply the power the beacon uses to transmit each broadcast. This has an effect on the battery life of the beacon but also controls the maximum distance a beacon can be detected at. In a smaller area a stronger signal is also able to bounce more before the signal dissipates but most importantly the signal strength is important when calculating a propagation model. Propagation models depend on the difference in a signal at one distance compared to at a further distance.
In this regard it is important to note that the propagation model becomes dependent on the transmitted signal strength. Should your system rely on the signal strength for a distance calculation then your beacons should be set to the same strengths. Otherwise your system will need to adjust the propagation model based on knowing the signal strength of each beacon. Otherwise beacons at different distances could be read as being at the same distance.

All values used in our data have also been adjusted by an offset of -45 RSSI, this is because the RSSI given by many devices is not the true power that is measured at the pins of the radio receiver[14]. This offset can be found by placing a beacon directly on the receiver and measuring the RSSI. RSSI is a scale from 0 to -100, where 0 is close and -100 is barely noticeable by the receiver. All the graphs in this paper (save two) are based on a sample of 50 measured averages which are shown from left to right in the order they were measured by the application. The vertical axis shows the RSSI value on this 0 to -100 scale. Since the RSSI scale is a hundred unit scale having a variation of 5 is the same as having a 5% variation, while 5% is not ideal it is acceptable, however variations of 10% or more would make a large difference in any distance calculations based on such an RSSI. All the tests have been performed with the beacon being 1 meter away from the smartphone but with the surroundings having different characteristics. In a perfect system the graphs would be similar both in their variation but also the average value of the RSSI since they are all at the same distance. As you will see this is not the case as the environment plays a large role in the RSSI value received.

The blue line in figure 1 is using a signal strength of -8 dbm and the propagation model that will be explained later in this section. The red line is the same beacon at the same distance but with the power turned up to 4 dBm. The tests were done in a larger room just to highlight that the propagation model is what is mostly affected by the broadcasting power. This was a simple line-of-sight test, almost an ideal environment and as we can see there are still variations of about 5 RSSI (excluding the one peak value per sample).

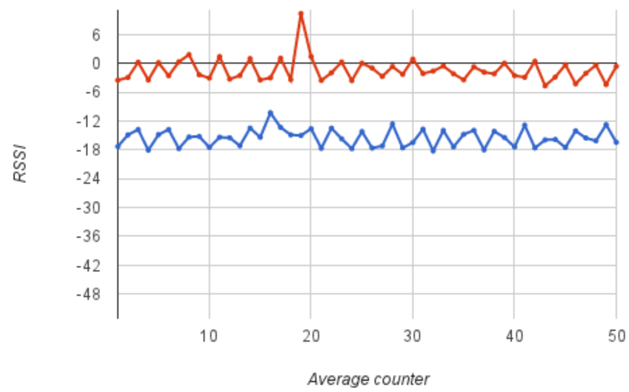

Figure 1. Two readings where the beacons had different signal strengths

The second setting is the broadcast interval and it also has a direct effect on the battery life of the beacon but it also leaves less time for signal to dissipate and may increase multipath issues. At the same time having a higher interval allows for more continuous data readings. There is a trade-off to be made between multipath increasing and the speed of readings. If you are performing averages on the signal then an interval that is too low would reduce the accuracy of a moving target depending on its speed and the interval chosen.

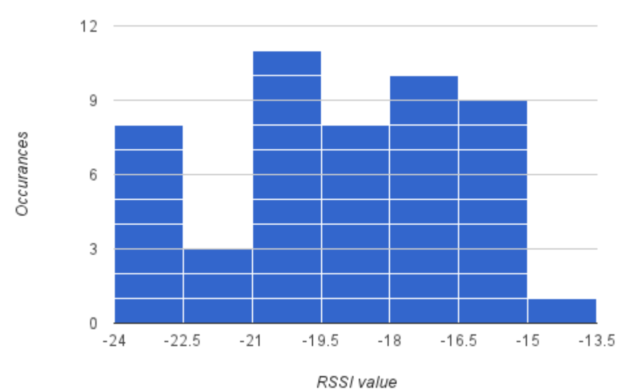

Figure 2. Readings with an interval of 2s

These readings were done in a smaller room and in the first set where the interval is longer we see a more even distribution of values with an overall slightly smaller range. In the second graph there are gaps in the values picked up and the range has grown, this may be attributed to the fact that signals that bounce can have the chance to either align their phases with the signal behind them which will

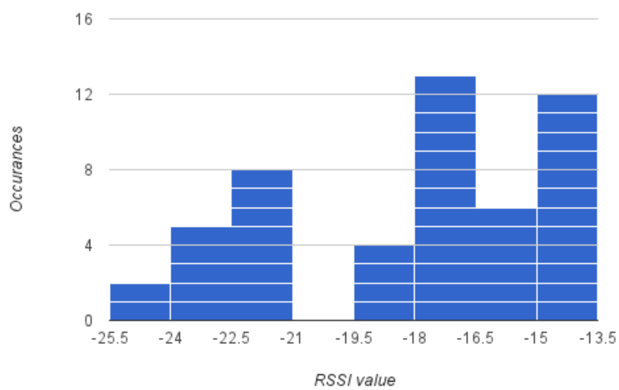

Figure 3. Readings with an interval of 50ms

amplify the result or collide and negate the signals. In an ideal system this graph would have a smaller range between values and the values would be evenly distributed over this range, with no gaps inside the range. In our tests we have maintained a signal strength of -8 dBm and an interval of two seconds.

In some regards indoor positioning can be easier than outdoor positioning. For example the area to cover is usually smaller, the boundaries are clearly defined and speeds are slower. However, topological constraints in indoor environments are much more complex than those in outdoor environments[18]. As this paper by Chawathe[18] shows, Bluetooth signals can be affected by a number of different attributes such as: room shape, presence of water, reflections, building materials, furniture, interference from other devices and people. These attributes affect the signals in different ways. Some of them create more bouncing like the reflections and some of them absorb the signals like water and people.

We conducted a series of measurements in rooms with some of these characteristics in order to identify the variations in the RSSI Values. We started from a round closed room similar to a small cave. We installed the beacon in the center of the room and started measuring the RSSI values at a stable distance of 1 meter from the beacon. We measured the RSSI and calculated an average from three RSSI values.

For figure 4 we collected 50 averages. As you can see the values are widely distributed for the same distance (1m). This means that in this configuration the raw data coming from the sensor cannot be used for distance calculations.
Then we moved to the second test configuration. We located a room where water was present to a great extent and we conducted the same test. The result we received can be seen in figure 5. The water area is surprisingly stable, there was little reflection in this area and the beacons were in line of sight from the smartphone. However, we see that comparing to the open area line of sight graph seen in figure 1 the values in the water areas are a lot lower, the signal is weaker.
Finally our last selected location was a big room containing a number of plants, rocks and a large variety of different surfaces in order to generate as much reflections as possible. The results of the test are shown in figure 6. As you can see in this room the values are not only unstable but also weaker than in previous areas due to the signal traveling.

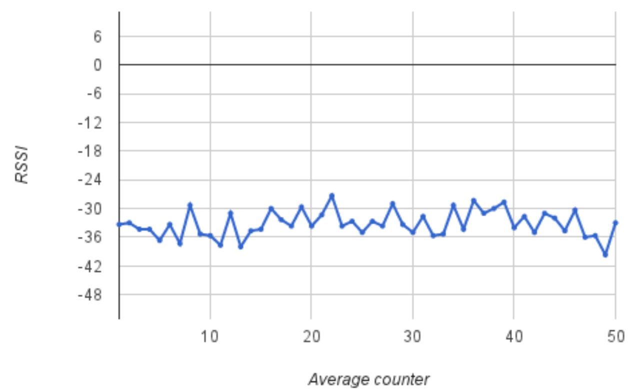

Figure 4. Cave test 1m no adjustments.

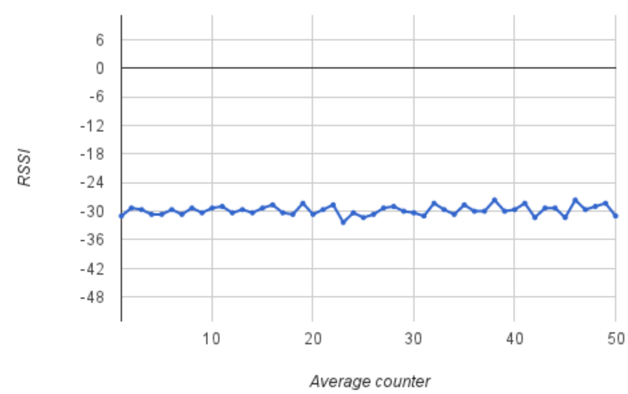

Figure 5. Water test 1m no adjustments.

It is clear now that the size and the topology of rooms can vary greatly; having a large effect on the RSSI readings. A propagation model is a term which describes the way signals travel through and are affected by topology of the area[12]. For our research we used a Log-distance path

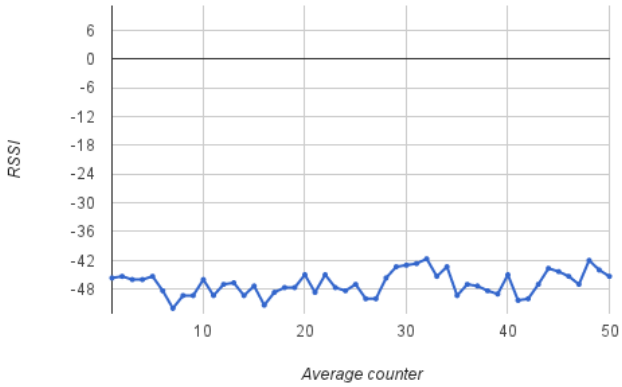

Figure 6. Obstacles test 1m no adjustments.

model which is expressed as follows:

$$P_L(d_i)[dB] = P_L(d_0)[db] + 10n\log_{10}(\frac{d_i}{d_0}) \quad (1)$$

Where d_i is the current distance between the units and d_0 is the distance of 1 meter. In order to calculate the path loss exponent, n, which is a constant used in describing the propagation model, we use the following formula:

$$n = \frac{\{P_L(d_i) - P_L(d_0)\}}{10\log_{10}(\frac{d_i}{d_0})} \quad (2)$$

For the free space propagation model n is calculated as 2[12]. Free space situations only happen in open spaces where the signal can travel in every direction without interruptions. After measurements in all three locations we conclude that the propagation average factor for this experiment is 2.3 m. After adjusting the propagation factor we made the same test and the RSSI values are affected as:

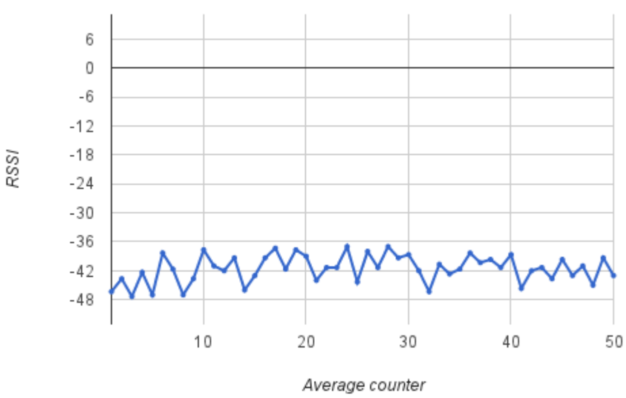

Figure 7. Cave test 1m with adjusted propagation model.

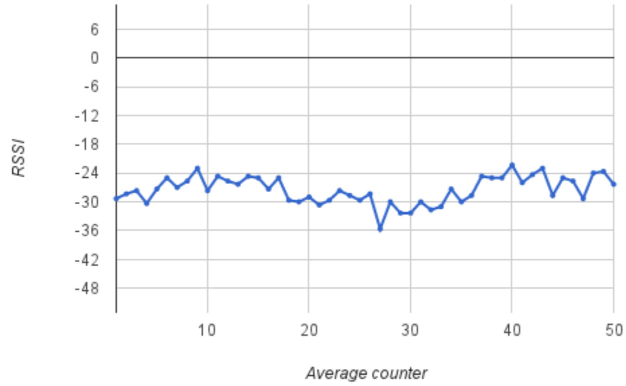

Figure 8. Water test 1m with adjusted propagation model.

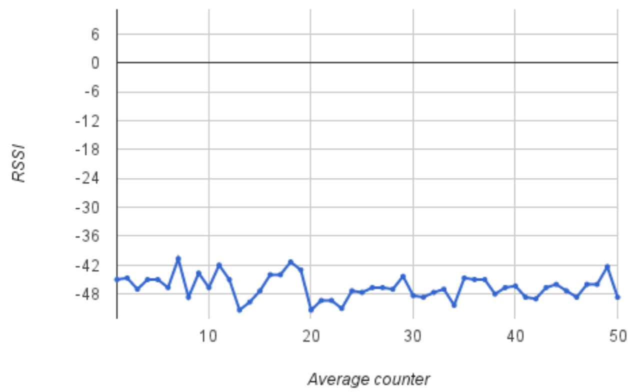

Figure 9. Obstacles test 1m with adjusted propagation model.

The results are contradictory to what we expected. In the cave area we achieved a smaller distribution of values but overall the values were lowered. Still the variation is higher than acceptable. In the water area the propagation model introduced more noise. The reflections area is somewhat unchanged. This means that the accuracy of the RSSI-based localization methods will still be affected by strong variations.

In order to address these problems we implemented an adaptive smoother, by making a fusion of the current value of the RSSI with the previous[7]. The idea behind this approach is that people cannot change locations very fast and the extreme RSSI spikes we get can be ignored. In order to implement this method we used the following formula:

$$RSSI_n = a * RSSI_n + (1-a) * RSSI_{n-1} \quad (3)$$

This means that the averaged RSSI value depends on both the previous averaged value and the most recently measured value. The variable a shows the degree of smoothening. If the value is close to 1, the new measurement barely plays a role in the calculation of the new average. For our case we used 0,65 in all our tests.

After implementing the smoother we performed the same tests again and the results are shown in the following graphs:

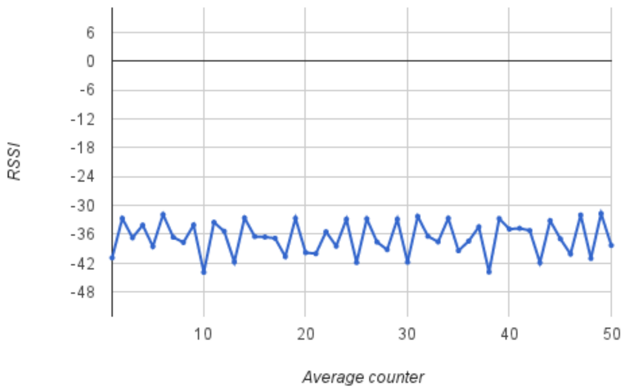

Figure 10. Cave test 1m with adjusted propagation model and lightweight filter.

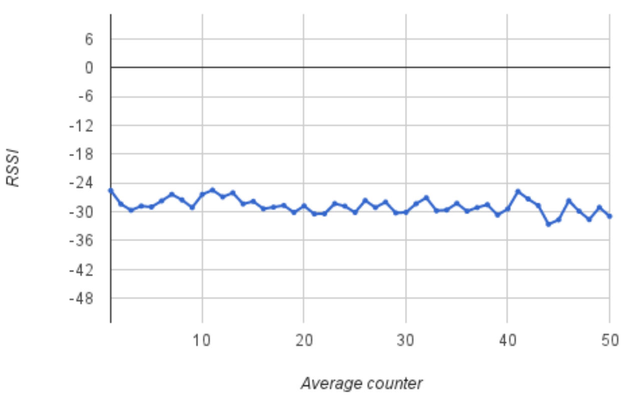

Figure 11. Water test 1m with adjusted propagation model and lightweight filter.

As we can see, after adopting this method the results have become smoother and many of the very inaccurate values have been removed. To conclude, we managed to improve and smoother the data but it is still uncertain if it can be used in indoor positioning algorithms to produce accurate results.

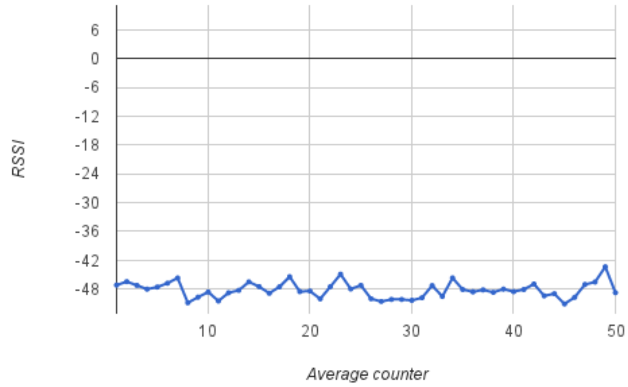

Figure 12. Obstacles test 1m with adjusted propagation model and lightweight filter.

5 Discussion

Despite somewhat inconclusive results from our data we hope to none the less provide some more insight and guidance into BLE and positioning systems with smartphones, both for practitioners and for researchers that may take this topic further.

What software techniques are viable to use with BLE and smartphones?
As we explained in our background section there are three types. BLE beacons were more or less made to offer proximity information out of the box when used with smartphones. For the geometric functions triangulation won't work as there is no directional antennae on most smartphones. While you can create beacons that send timestamp information (even though synchronizing such a system would be difficult) as long as the smartphone API does not provide the ability to read these timestamps by BLE scans it will be of little use. It is worth noting that BLE scans are different from Bluetooth connections, BLE beacons may offer the ability to set up a connection and read these values (called characteristics) but by doing so we lose a key quality of using BLE, the connectionless readings.

Instead these kind of systems are limited to using RSSI based techniques be used. Such as trilateration or scene analysis methods with the distance measurement based on the signal. While these both rely on the quality of the signal received they can also be made flexible to allow for errors. For example while trilateration theoretically offers the most precision it is also very vulnerable to errors in the numbers as even minor errors may results in a unsolvable equations. This can be overcome by using for example a least squares formulation, which also adds the benefit of being able to use more than three reference nodes to improve accuracy[19]. Approaches like these one do however increase the computational complexity of the trilateration algorithm on top of any computations to adjust the signal quality (some of these may perhaps be precomputated to trade some computation time for storage space).

The other possibility is scene analysis, BLE signals can be used to create fingerprints on the smartphone. However, they are also affected by the same multipath issues. As long as the fingerprint can remain somewhat stable then it can possibly be used to find close neighbors by some of the methods mentioned in this paper. Scene analysis takes more preparation but is less computationally complex at run time which perhaps would allow for more of the smartphones resources to be devoted to signal improvement computations. Scene analysis will still be affected by changes in the way signals find their way to the receiver by multiple paths and this may lead the algorithms to find an entirely different neighbor.

How can the quality of BLE signals be improved?
As we have seen there are a number of different attributes that affect the signal quality. Most of them can be identified and there are techniques that can help in overcoming them. Propagation models can be helpful in giving a general sense of how the signal travels in a room. Moreover this can also provide more information on the way that the beacons should be distributed inside the room. We believe having the same propagation model for every room in our tests created problems so every room should have its own calculated propagation factor. Much more effort would need to be put into finding a good way to model each area that this kind of system would operate in. Creating multiple readings of the propagation exponent for each room and trying to consolidate it into one value or building a flexible system that keeps track of propagation zones rather than rooms could also be an option but complexity of the system is rising quickly.

Additionally, more advanced Kalman filters and statistical analysis can be used to filter out the noise from bouncing signals. The fact that users cannot jump between locations is very helpful in this approach. Beyond these kind of filters and propagation modeling there is little that can be done to negate multipath issues and more work needs to be done into how to effectively counteract multipath in indoors environments but perhaps more specifically for smart devices where a developer doesn't have direct control over the signal processing unit. This could be achieved by the smartphone platforms providing more control over the hardware through more advanced APIs or by research into multipath countermeasures for smartphones.

Is BLE a suitable choice for indoor positioning systems using smartphones?
The technology opens up new horizons and some of the prospected application areas are interactive tour guides, museums and shopping centers. BLE has a few simple advantages over other hardware technologies. It's been developed to use less power so the battery life of both the transmitter and the receiver will last longer. The cost of a single beacon is comparatively cheap. Maintenance of the beacons is minimal, their MAC addresses may need to be stored in a database but there is no need to set up any sort of network to use them and they come ready to use out of the box in most cases. They offer connectionless readings by receivers. Together with a smartphone you get a platform that almost provides its own hardware as many people already own a smartphone and most new smartphones are BLE compatible. They are also able to provide micro location proximity quite easy by turning their power down, creating a very small zone that can trigger events on the phone.

For further and more precise distance positioning we believe simply that it is no worse a hardware choice than regular Bluetooth which has seen some successful use without these benefits. The biggest problem that we see for the use of Smart technologies are the smart devices themselves. As we mentioned in the background section many of the techniques available to mitigate multipath issues rely on having control of the signal processing unit which we don't on a Smartphone (at least in the current setup of smartphones and platforms on the market). These limitations apply also if one were to use WiFi or other signal technologies as the smartphone platforms don't provide direct control. In our background we also briefly mentioned the trade of between hardware benefits and software possibilities. Anyone looking to use Smartphones in such a system should be very aware of these limitations. While there are options when it comes to hardware, possible algorithms to use and currently a few techniques available to reduce the multipath issues Smartphones still apply great limitations to these systems and that the multipath countermeasures come at a cost for performance. Not everything can be fixed with software solutions, as such it is very important to have a clear set of requirements when it comes to performance and also the accuracy you need from the system before making choices in hardware, both with regards to which signal technology you use but also in the choice of using Smartphones or developing your own receiver hardware. Keep in mind the benefits but also the limitations of each choice.

6 Conclusions

It is clear now that indoor positioning is a difficult task. Topology constraints in indoor environments are much more complex than those in outdoor environments. Every room distributes and affects the signals in a different way. This means that propagation models must be more precise and that even a small area can have large differences in how the signal bounces to position A and position B. Multipath is a large issue and there exists a lack of good ways to counteract these on Smartphone platforms, while creating advanced propagation models and using statistical filters may improve the situation they are currently not a good enough solution.

We made an attempt to evaluate the Bluetooth Low Energy protocol in conjunction with Smartphones, the way it works in indoor environments, how it is affected by multipath and explore the ways of improving the quality of the received signals by analyzing the RSSI values received. This research paper can be used as a point of reference for future software developers in the area of indoor positioning systems and Bluetooth proximity zones that would make use of Smartphones.

In order to conduct this research we first built a smartphone application to allow us to make measurements of BLE signals as well as implementing ways to improve them. Data was collected from these tests and used to guide the direction of further improvements. We conducted a series of tests in a number of different indoor environments in order to identify how the signals are affected. We looked into the possible ways to improve the data as it is not stable as raw data. Some possible remedies are statistical filters and propagation models. We implemented a simple form of statistical filter and measured the factor for our propagation model but due to Smartphone platform constrains it was not possible to perform direct signal processing. This may hint that for these kinds of positioning techniques Smartphones are not a suitable platform and that they should be used in conjunction with BLE for what BLE was originally designed for, micro-locations through small proximity zones.

There remains work to be done as our results were inconclusive but in the right direction. Further effort must be put into modeling the propagation of areas individually and refining the filters and adjustments that are applied to the signals to improve their stability. Beyond creating improved models and filters these also need to be optimized so that they may be used without being to resource heavy as the actual positioning algorithms can be heavy already. As a final suggestion we believe future work should be put into finding pure software solutions to counteracting multipath issues as this would allow us to make use of all the Smartphones out there for these kind of systems, perhaps independent of the signal broadcast technology used and that this may lead to a less complex choice when it comes to deciding your hardware platforms.

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