University of Bergen

Master Thesis

Digitalization of Retail Stores using Bluetooth Low Energy Beacons

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Author:
Kristian Hellum

Supervisor:
Richard Moe

Department of Information Science and Media Studies
Faculty of Social Sciences

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Abstract

This thesis explores the domains of retail stores and the Internet of Things, with a focus on Bluetooth Low Energy beacons. It investigates how one can use the technology to improve physical stores, for the benefit of both the store and the customers. It does this by going through literature and information from academia and the relevant industry. Additionally, an interview with an expert in the retail domain is conducted, and a survey consisting of a series of interviews and questionnaire with what can be considered experts in the IT domain. A prototype app called Stass is developed, the app demonstrates some of the usages of the technology and is also used for evaluating the performance of the beacons.

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My friends, family and my close ones for being there when I need you.

Contents

List of abbreviations

API	**A**pplication **P**rogramming **I**nterface
BLE	**B**luetooth **L**ow **E**nergy
CMS	**C**ontent **M**anagement **S**ystem
DS, **DSR**	**D**esign **S**cience **R**esearch
ESL	**E**lectronic **S**helf **L**abel
GDPR	**G**eneral **D**ata **P**rotection **R**egulation
GNSS	**G**lobal **N**avigation **S**atellite **S**ystem
GPS	**G**lobal **P**ositioning **S**ystem
GUI	**G**raphical **U**ser **I**nterface
IMES	**I**ndoor **M**essaging **S**ystem
IoT	**I**nternet **o**f **T**hings
IPS	**I**ndoor **P**ositioning **S**ystem
JSON	**J**avaScript **O**bject **N**otation
LiFi	**Li**ght **F**idelity
POI	**P**oint **o**f **I**nterest
RFID	**R**adio-**F**requency **Id**entification
RTLS	**R**eal-**T**ime **L**ocation **S**ystem
RQ	**R**esearch **Q**uestion
SDK	**S**oftware **D**evelopment **K**it
SLAM	**S**imultaneous **L**ocation **a**nd **M**apping
UUID	**U**niversally **U**nique **Id**entifier
UWB	**U**ltra-**W**ide**B**and
VLC	**V**isible **L**ight **C**ommunication
WiFi	**Wi**reless **Fi**delity
XML	**E**xtensible **M**arkup **L**anguage

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1 Introduction

It's been nearly two decades since the year 2000, and the evolution in the digital sphere since then has been astonishing. An increasing amount of objects in and aspects of our lives are connected to the internet. With our smartphones always with us, most are but a small arm-movement away from the internet 24/7.

For the consumers, technologies like smartphones and the internet have had quite an impact when it comes to shopping. Online stores and apps for shopping can provide the consumers with a seemingly never-ending selection of products, across the borders of nations. This has in turn caused prices to go down, the stores to have better conditions, return policies and focus on good experiences for the customer.

The idiom the jungle telegraph refers to a network of communication between people, often informal and in a manner that seem like gossip. If you have had a bad experience in a store, and tell people about it, the jungle telegraph is in effect. The jungle telegraph has in the last decade become drastically more important. Turn the time back, and a dissatisfied customer might share the bad experience with his close ones, his close ones share his bad experience to others, and it slowly but surely spreads throughout the social circles. In these days however, one dissatisfied customer can make quite the story with internet news, social media and various services that aim to help its users have good experiences by presenting reviews and rating. Paradoxically, the dissatisfied customers seem more prone to give the store a bad reputation, than a satisfied customer seem to give the store a good one. We expect good experiences, and if we are not satisfied when leaving the store, it is deemed subpar.

Online stores have many benefits like never being closed, it is easy to compare prices of its competitors while browsing the internet, and as they have large storages they tend to have a wider selection of products than its physical counterparts.

As a result most retail chains have established an online store. The chains physical stores have longer opening times, they increase in size and selection of products to keep up. All of these aspects that are increased also increases the amount of work that has to be done. Digital shelf-labels are one aspect of these stores that have become increasingly popular the last years, as they lessen the workload of having correct prices. They all compete to have the lowest prices, making it even more important that they can be updated easily. However, as the sizes of the stores and the selections of products increases, it gets harder for the customer to navigate both the store and the products. It also gets more difficult for the employees to have detailed knowledge of all the products.

For the physical stores to keep up with online stores, they need to use methods to provide customers with a reason to buy products from physical stores. What can be done and how can it be done? Why should the store do it and will it work? These are the kinds of questions this thesis seeks answers to.

1.1 Motivation

The motivation for this project came from my background of working part-time in a retail store for the last seven years. During the seven years, I finished high school, and have been studying Information Science at bachelor and now master level. Through the years I have picked up a thing or two about how stores function, as well as learned quite a bit about information technology. With an interest in smart homes, Internet of Things (hereby IoT) and the likes it seemed as good as option as any to explore the domain of this thesis. How can one use technology to improve retail stores? A recent example is Amazon's cashier-free Amazon Go (Amazon, 2017). Additionally, the Bluetooth Low Energy (hereby BLE) beacon technology is a relevant and promising technology that with its many use cases are interesting to investigate.

The main artifact in this thesis, Stass (**St**ore **ass**istant), came from an idea I had a few years back while attending one of the bachelor level system development courses. The idea was basically to have an indoor map with navigation based on checkpoints to help users navigate the venue. The user would have to press a check-in button at the checkpoints in the venue, to calibrate the position on the map and be able to navigate the environment. We did not pursue the idea in the system development course. At a later point in time I discovered the BLE beacon technology, which I thought would be a better approach, as one could do the positioning without the user having to manually calibrate the positions. The whole system could be fluent and be able to track the user, an Indoor Positioning System working as smoothly as the Global Positioning System. Additionally, I thought that the technology could be used to improve retail stores and how the customers are able to learn about products and use technology to assist themselves.

1.2 Research problem and questions

This section covers the research problem, and the research questions that is designed to investigate the research problem.

Research problem

How can BLE beacon technology be used to enhance retail stores so they remain competitive with online and physical competitors, and benefit both the store and the customers?

Research questions

RQ1: Does BLE beacons provide sufficient technological basis for micro-location and micro-positioning in retail stores?

RQ2: Would a smartphone application that utilizes a retail store's information about products, offer the customers assistance and help them navigate the store, be helpful for the retail store's customers? And would the customers use such an application?

RQ3: What are some of the functionality one can have in a system using IoT together with the retail store's currently existing and in the future potentially available data?

RQ1 is mainly answered through conducting tests that investigate the performance of the BLE beacons. RQ2 is mainly answered through an expert interview, and a survey consisting of shorter interviews and a questionnaire. RQ3 is mainly answered through investigating literature in the industry and academia, from insights from the interview and survey and through the development of the prototype app.

The main artifact is a prototype Android app, and the concepts that naturally would come with an app of its nature.

The prototype app played a part in answering all the research questions, it helped answer RQ1 as the data needed to answer the question was collected through the app. The app helped answer RQ2, as it was presented to the interviewee and participants of the survey, which gave feedback, insight and data. It also helped answer RQ3, as the development and implementation demonstrated the feasibility for some of the concepts.

2 Research Method

This chapter goes through the research methods used in this project, as means to answer the research questions seen in section 1.2.

2.1 Types of Research

There are many different approaches to doing research, just as there's often multiple approaches to solving a problem. In the next subsections clarifications on different aspects and ways of doing research are presented.

2.1.1 Quantitative and Qualitative

In this project, both quantitative and qualitative research methods are used, and both quantitative and qualitative data is generated and collected.

Quantitative research is characterized by collecting vast amount of data, that are meant to be used to aid the researcher explain why things are the way that they are (Bryman, 2016). Oates (2006) states that quantitative data means data or evidence based on numbers, and that this is the main kind of data produced by experiments and surveys. The analysis of quantitative data comes by looking at patterns in the data and drawing conclusions from it. Hellevik (2000) makes the point that in quantitative research the researcher acquires comparable data on a vast amount of units, expresses the data in form of numbers and do a statistical analysis of the patterns in the data. This project gathers quantitative data from the questionnaire used in the survey, and the performance testing of the beacons.

Qualitative research is by Hellevik (2000) mentioned as a type of research that has fewer units with more variables/data, and the data for the units aren't directly "comparable" values but instead often text and information. He also states that although most people often would prefer one or the other approach, one can for instance use qualitative research to get a better understanding of the phenomenons and concepts, and then do quantitative research once the underlying concepts are better understood. Oates (2006) states that all non-numeric data is qualitative data, text, images, sound and the likes. The qualitative data needs to be analyzed, and although one can apply quantitative analysis on qualitative data, the main analysis often involves abstraction of the themes and patterns in the data that the researcher finds important to the topic of research. Bryman (2016) states that some characteristics of qualitative data is that it is often rich and deep, in contrast to the quantitatively hard and reliable data. He also stated that qualitative research often is less structured, and that it focuses on the meaning rather than the behavior of the people. He also reminds the readers that the differences isn't all black and white, this or that, there are fluctuations and variety in the research methods.

This project gathers qualitative data from the interview, the literature review, and from parts of the questionnaire and interview from the survey.

The quantitative data in this project will be analyzed in terms of patterns and interesting data-points in the comparable data, while the qualitative data will be interpreted and analyzed to discover new information that can be helpful for answering the research questions.

2.1.2 Descriptive

Hellevik (2000) states that descriptive research is often used when the research problem is more precisely formulated, as the researcher then can conduct a thorougher and more systematic study of the research objects, in some cases the researcher will focus on accurately describing properties of the objects. According to Oates (2006) descriptive studies lead to rich and detailed analysis of a particular phenomenon and its context. Descriptive research is about describing existing phenomenons in the world, it is more concerned with the what, rather than the why, when and how.

2.1.3 Explanatory/Causal

Explanatory research tries to show and explain causes to the patterns discovered, this type of research is common when relatively vast amounts of knowledge on the subject is present, and it gives grounds to create hypothesis's or cause-models one can test (Hellevik, 2000). Oates (2006) talks about exploratory case studies when he states that the analysis in such studies: *"seeks to identify the multiple, often inter-linked, factors that had an effect, or compares what was found in the case to theories from the literature in order to see whether one theory matches the case better than others."*. Explanatory research is about causality, cause and effect, and identifying and explaining them and their relationships for the concepts that are investigated.

2.1.4 Exploratory

Hellevik (2000) explains what an exploratory study means in his book about the scientific methods in sociology and political science, that if a researcher lacks the overview over a domain, he can do an exploratory investigation or study. In such an investigation the researcher tries to more precisely formulate the research problem so that it can be further examined, he can achieve this by for instance reviewing the literature and by interviewing experts and informants. Oates (2006) states that exploratory studies help a researcher better understand a research problem. Exploratory research is about discovering and learning aspects, details and information about the problem domain one are exploring.

2.2 Design Science Research

This thesis searches to find ways to strengthen the retail stores position in an ever increasingly digitalized world. There are many different concepts and themes addressed, which has certainly enlightened me, and might provide some insight to others investigating technology in the retail store domain, beacon technology and indoor positioning. The research design in this thesis builds onto the design science framework, although not slavishly to each detail, it does serve as the foundation and framework.

The design science research (hereby DSR) in this project incorporates some of what Iivari (2015) illustrates as Strategy 1 for DSR: *"In the first strategy, a researcher constructs an IT meta-artefact as a general solution concept possibly to be instantiated into a specific solution concept or a concrete IT artefact (application) to be adopted and used in a specific context."*. Which is what the artifact in this thesis is intended as, it is made as a general solution presenting different concepts, where those concepts could be used in an actual system. An IT meta-artifact, with a real system implementation for several of the features and concepts.

2.2.1 Learning via making

Oates (2006) has a chapter in his book Researching Information Systems and Computing, which addresses what he calls Design and Creation Research. He begins with defining the approach and discussing the importance and need for the research aspect in IT projects. The artifact of this project would be an instantiation, which Oates explains as: *"a working system that demonstrates that constructs, models, methods, ideas, genres or theories can be implemented in a computer-based system."*. Further he states a project must contribute to knowledge if it is to be considered research. That contribution to knowledge could be a combination of the construct, model, methods and instantiation. For many of the projects in IT to be called research, rather than just an illustration of technical ability the researcher must also demonstrate academic skills like analysis, explanation, argument, justification and critical evaluation. This project would fit what Oates describes as a research project using the IT application as a vehicle for something else: *"A project where the contribution to knowledge is based on a literature review and/or field research, but the conclusions drawn from this work are illustrated via a prototype IT application."*. Learning via making is what Oates calls using a design and creation strategy for the research, as he refers to Vaishnavi and Kuechler (2004) and their five steps in the iterative approach to problem-solving: awareness, suggestion, development, evaluation and conclusion. The five steps include things like recognizing and articulating the problem, finding an idea to have the problem might be addressed, implementation and development of the idea, evaluation of the created artifact and a conclusion where the knowledge gained is presented. Oates (2006) finishes his discussion and presentation of the five steps by stating that: *"These steps are not followed in a rigid, step-wise fashion. Instead they form a more fluid, iterative cycle..."*, the fluidity and iterative aspects comes naturally as new knowledge is acquired by the researcher throughout the process.

2.2.2 The DSR guidelines

In Hevner et al. (2004) seven guidelines for design science was presented, which have basis in a fundamental principle of design-science; *"The fundamental principle of design-science research from which our seven guidelines are derived is that knowledge and understanding of a design problem and its solution are acquired in the building and application of an artifact."*. The guidelines are today widely accepted and used, and have been for a while. As Hevner and Chatterjee (2010) put it: *"...the seven guidelines in the 2004 MISQ paper have been largely accepted as integral to top quality design science research..."*. The guidelines presented by Hevner et al. (2004) and how they fit with the research process of this thesis will be covered in the remaining part of this section.

Design as an Artifact
The first guideline states that a DSR project must create a viable artifact in the form of a construct, model, method or instantiation. The main artifact of this thesis will be in the form of a concept and a proof-of-concept Android app, with some functionality implemented and some merely described. The artifact will be used in various ways to evaluate and draw conclusions to the research questions. In other words, this thesis construct an artifact that has two sides, one side is a construct and the other an instantiation of that construct. As mentioned Oates (2006) stated that constructs are concepts or vocabulary, and instantiations are working systems that demonstrates that the constructs can be implemented.

Problem relevance
The second guideline states that the objective of DSR is to develop technology-based solutions to important and relevant business problems based on technology. In order to do so one needs to acquire knowledge, which enables the development and implementation of the solutions. This thesis acquires the knowledge through reviewing the academic literature and taking a closer look at what the industry has to offer. Additionally, the development of the artifact, the artifact itself, the expert interview and the survey also serves as data and information generating sources which helps with acquiring knowledge.

Design evaluation
The third guideline states that the utility, quality and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods. Hevner et al. (2004) mentions that evaluation is a crucial component of the research process, and that there is multiple way of evaluating the design and artifact. They state that for instance IT artifacts can be evaluated in terms of functionality, completeness, consistency, accuracy, performance, reliability, usability, fit with the organization, and other relevant quality attributes. In the section on design evaluation there is also a table presenting design

evaluation methods, and the parts seeming most appropriate to compare to is in the experimental and descriptive parts. A controlled experiment of sorts will be conducted, by testing the beacons performance through the artifact. I would argue that the descriptive research's informed argument, where one uses information from the knowledge base to argue for the artifact's utility also is to some extent what is being done here. The second method in the descriptive part is scenarios, I wouldn't say that detailed scenarios are constructed to demonstrate the artifacts utility. However, a general picture is drawn, trying to illustrate the possibilities and potential that lies in the technology.

Research contributions
The fourth guideline states that effective DSR must provide clear and verifiable contributions in the areas of the design artifact, design foundations and/or design methodologies. If there is no contribution of knowledge, one can argue that it isn't research. What the knowledge is might vary, and it might not always be new and revolutionizing. The three main types of research contributions in DSR is the artifact, foundations and methodologies, and the criteria for assessing the contribution focus on representational fidelity and implementability (Hevner et al., 2004). The contribution in this thesis comes from the artifact, the concept of what the app should be, the methods used to generate data and the tests and results from performance testing the beacons. It builds onto the work done by Saetre (2017); Godoy (2017) and can be worked onto further in the future by others.

Research rigor
The fifth guideline states that DSR relies on the application of rigorous methods in both the construct and evaluation of the design artifact. Which means that the methods used should be thoroughly and carefully executed. It is about the researcher using the tools in the knowledge base and building the new research with help of existing and proven research. This thesis bases itself onto such existing knowledge, from the prototype development, to interviews, and the collection of quantitative and qualitative data. Although there are room for creative and original approaches, the foundation of methods used are rooted in the research methods from the knowledge base.

Design as a search process
The sixth guideline states that the search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment. Further Hevner et al. (2004) states that design science is inherently iterative, and that design is a search process to discover an effective solution to a problem. The prototyping and development in this project were iterative in nature, and it was a continuous process of either acquiring new knowledge or utilizing the acquired knowledge to improve the prototype. For each iteration there were generally improvements, which were a step in the direction of discovering an effective solution.

Communication of research
The seventh guideline states that DSR must be presented effectively to both technology-oriented and management-oriented audiences, with the technology-oriented audience

having sufficient detail needed to be able to implement the described artifact. The management-oriented audience need sufficient detail to able to determine if the solution is worthwhile, and if the organization should commit to it. I would argue that this thesis contains the information these two audiences are interested in. From the technical perspective a lot of possibilities, potential and options with the technology are discussed, as well as solutions and concrete details. Similarly, the information needed for the organizations (retail stores) to incorporate and commit to the usage of the technology is present. Not in the form of a done product, or precise formulation of how to achieve all the concepts presented. But rather as a presentation of what can be done, why it is a good idea, and what obstacles one might find in the process of realizing the concept. I firmly believe that if the obstacles can be overcome and solved, in a delicate and smart fashion, there are tremendous value in the technology.

2.3 Research Design

According to Oates (2006) a research methodology is the combination of research strategies and data collection methods that is used in the research project. This thesis goes a bit outside the framework but uses methods of data collection based on science. The research design of this thesis consists of the parts covered in this section.

2.3.1 Literature review

A review of the literature is conducted, as one of the main parts of data collection. Oates (2006) states that the aim is to present evidence that supports the claim that this thesis creates new knowledge, the review of literature is conducted in chapter 3 called 'State of the art'. The chapter looks at relevant information in academia and the industry.

2.3.2 Prototyping

In the definition on prototyping in the UXL Encyclopedia of Science 3rd ed. (Edited by Blackwell, Amy Hackney and Manar, Elizabeth) (2015), it is stated: *"A prototype may replicate just one portion of a design. It may create the look of the object without its functionality, or the functionality without the look. A fully functional prototype is a full-scale working model of the final product."*. By that definition, the application that is created can be categorized as a semi-functional prototype. It does not have all the functionality that one would expect from an app of its nature, but it does have several of the key ones. Prototyping is about making small functional or semi-functional pieces of a system, one creates an initial incomplete version of the imagined or planned system, that can be used to modify and adjust the initial plans and ideas for that planned system. The prototype is gradually modified until a satisfactory implementation is produced (Oates, 2006). So one starts with an objective or idea, and creates a simple part of the whole system, and from there iteratively adjusts and changes accordingly to the new knowledge that is being acquired. The prototyping in this thesis would be closest to what Davis (1992) described as evolutionary prototyping and throwaway prototyping, as initially a throwaway-like approach was used. In the early stages the requirements weren't well understood, and the development were "sloppy", but it was a means to familiarize myself with the technology that were going to be used. As a couple simple functioning prototype parts were created, and the technology and environment became familiar a more evolutionary-style approach were taken. Davis (1992) describes evolutionary prototyping as a rigorous approach, which focus on implementing the parts that are well understood and is built in a quality manner. In the definition on prototyping in the UXL Encyclopedia of Science 3rd ed. (Edited by Blackwell, Amy Hackney and Manar, Elizabeth) (2015), it is stated: *A prototype may replicate just one portion of a design. It may create the look of the object without its functionality, or the functionality without the look. A fully functional prototype is a full-scale working model of the final product.* By that definition, the application that is created can be categorized as a semi-functional prototype. It does not have all the functionality that one would expect from an app of its nature, but it does have several of the key ones. Prototyping is about making small functional or semi-functional pieces of a system, one creates an initial incomplete version of the imagined or planned system, that can be used to modify and adjust the initial plans and ideas for that planned system. The prototype is gradually modified until a satisfactory implementation is produced (Oates, 2006). So one starts with an objective or idea, and creates a simple part of the whole system, and from there iteratively adjusts and changes accordingly to the new knowledge that is being acquired. The prototyping in this thesis would be closest to what Davis (1992) described as evolutionary prototyping and throwaway prototyping, as initially a throwaway-like approach was used. In the early stages the requirements weren't well understood, and the development were "sloppy", but it was a method of familiarizing myself with the technology that were going to be used. A couple of small, simple and functioning prototypes were created, and the technology and environment became familiar a more evolutionary-style approach were taken. Davis (1992) describes evolutionary prototyping as a rigorous approach, which focus on implementing the parts that are well understood and is built in a quality manner.

2.3.3 Beacon performance testing

The experiment of testing the performance of the beacons builds onto the work of Saetre (2017); Godoy (2017) and attempts to take it one step further. A newer version of the beacons, more beacons and a newer smartphone than were used in their thesis is examples of variables that could provide interesting results. Since the testing would likely produce more accurate and precise result, due to the technology they used being a generation older. Why the evaluation and testing of the beacons performance was seen as useful was nicely put by Saetre (2017); *"This was done in order to collect our own quantitative data in a meaningful manner, which in turn creates some empirical data as to the viability and accuracy that the beacons are able to offer us, when used in a practical setting. This evaluation method is a quantitative form of data gathering..."*.

2.3.4 Expert interview

A semi-structured interview with an expert is conducted, serving as the main basis of the qualitative data. The interview was conducted to investigate the opinions, beliefs and knowledge of a veteran in the retail grocery store segment. Both with regards to the technological evolution that has been ongoing for the last decades, and for the digital evolution that is ongoing.

2.3.5 Survey

A survey was conducted, providing both quantitative and qualitative data that are relevant to answering the research questions. It was conducted in a setting similar to user-testing, but the HCI component were paid no attention to. The user-test resembling part was about the part-takers of the survey getting a context that enabled them to answer the questionnaire. The context was provided by them exploring the app and the concepts, and through the unstructured interview that were conducted simultaneously. During the interview anything interesting were written down, negative and positive feedback, new ideas and so forth. The unstructured interview gave some additional qualitative data. At the end of the survey the part-takers went through the questionnaire which generated both quantitative and qualitative data, section 7.2 covers the conduction and results found in the survey.

3 State of the art

In this chapter we will look at the state of the art, it will cover some basics about Bluetooth and beacons, and lay grounds for some technologies and terms that is useful to be aware of. Additionally, different technologies and relevant projects from the industry and academia are covered. In the chapter there are a lot of examples of functionalities and features that could be utilized in the artifact, especially in sections 3.4 and 3.5. Both information and answers that are relevant to RQ3 is to be found in the chapter, however it also provides information relevant to the other research questions as well.

3.1 Beacons

In this section we will look at and explain the concept of beacons and Bluetooth. The beacons used in this thesis comes with Bluetooth, and some of them also have Ultra-WideBand (hereby UWB) capabilities. Therefore, UWB will also be covered in this section, as opposed to the alternative technologies section.

3.1.1 Beacon

A beacon is a device that broadcasts a signal, sometimes the signals are broadcasted by predefined intervals or conditionals. What beacons broadcast can differ, it for instance can be radio, light or sound waves. These days when the term beacon is mentioned, people tend to think about small devices that broadcast for instance Bluetooth signals. It enables other devices to detect its presence, with the possibility of the beacon not knowing about the device. Like how a ship might see the lighthouse, which is a beacon, but the lighthouse might not see the ship.

3.1.2 Bluetooth

Bluetooth is a standard for wireless data exchange over short distance, and it is a common technology found in many of the devices we use each day. For instance computers, smartphones, wearables, gaming consoles, headphones, printers, cars and what seems to be an endless range of devices. As the IoT is still on the rise, the amount of devices with Bluetooth capabilities does not seem to be decreasing any time soon. Bluetooth transmits low power radio-waves, and have multiple use cases, from BLE and proximity applications to file transfer between devices. It is estimated that by 2020 we will have more than 20 billion IoT devices (Aruba, 2017).

3.1.3 Bluetooth Low Energy

In 2011 the Bluetooth Special Interest Group (hereby Bluetooth SIG) announced that they were extending the Bluetooth brand with Bluetooth Smart for devices which revolve around sensors and information gathering and Bluetooth Smart Ready for phones, PC, TV and such devices (Bluetooth SIG, 2011). Later on, the brands Smart and Smart Ready were phased out and integrated as a part of the Bluetooth brand, it was however the introduction of the technology to the world. And it was what we today simply know as Bluetooth Low Energy or BLE. Prototypes of devices with the technology was actually displayed as early as 2008, at the expo Wireless Japan 2008 (Bluetooth SIG, 2008).

3.1.4 The BLE beacon technology

BLE has many use cases, one use case many has picked up on is the ability to contextualize the real world. The idea is that one has tiny devices transmitting its presence (by sending low powered Bluetooth signals), and then we have another device that is able to identify those signals. Once the signals are identified one can do some action based on what those signals are and what device broadcasted them. What information the Bluetooth signals contain depends on the protocol it uses. In 2013 Apple announced its iBeacon protocol, the most common protocols are the already mentioned iBeacon and the competitor Google's Eddystone protocols. The beacons often come with more than simply BLE broadcasting capabilities, many of them have additional technology on-board like temperature sensors, light sensors and accelerometers. The shapes, looks and sizes of the beacons vary.

3.1.5 Provider of the beacons

Today there are several companies working with BLE beacons, both on the hardware and component side and the software side. The amount of companies who specialize in solely BLE beacons aren't too many, as the technology and companies still seem to be maturing. Those waiting patiently for the beacon-revolution, might have to be patient for a little longer.

Estimote is one of the major players in the beacon-industry today, they provide different kinds of beacons that are useful for different kinds of problems and tasks. As well as providing hardware they also provide software and a content management system (hereby CMS) to help people make use of the technology. A quick search on Google reveals that there exist several companies providing similar products and services, both on the hardware and software side. The beacons used in this thesis are four of their Location Beacons with BLE and UWB, and three with only BLE. The beacons can be seen in the picture in figure 3.1.

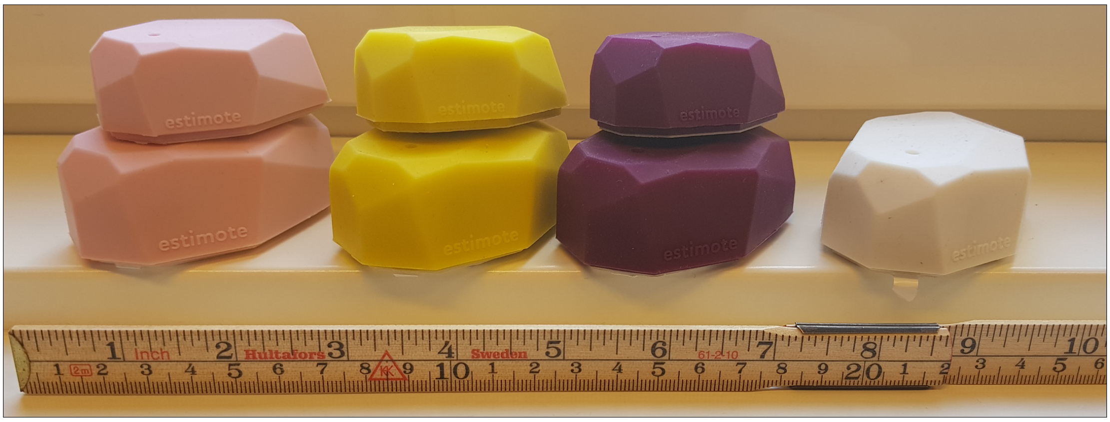


Figure 3.1: The location beacons from Estimote, the ones with UWB at the bottom

In section 3.4 an overview of what goes on in the industry is presented, as there are a lot of relevant information to be gained from investigating them and what they are doing. Specifically the companies who provide hardware, software, technology and solutions that can be used with beacons and in situations relevant to the artifact will be looked at. Hardware manufacturers/suppliers and companies who makes the circuit boards and the radio transmitter chips will not be covered.

3.1.6 Different kinds of beacons

Some obvious advantages of BLE beacons are that they are small, relatively cheap, light and can be mounted in various places and run on batteries up to five years. And they can be used with every mainstream smartphone on the market. How long the battery of a beacons will last depend on multiple factors, like advertising intervals, sleep modes, information that is advertised, potential additional technology and so forth.

Different kinds of beacons are available on the market, and specific use-cases fit different beacons better than others. As mentioned, in this project Estimote's location beacons have been used, three normal location beacons, and four location beacons that also come with UWB technology. These are relatively similar, but they have some differences. The beacons with UWB can be used to map out a room automatically with Estimote's iOS app also called Estimote. With the non-UWB beacons you are able to map out that space manually with the same app, which requires more work from the user. You are not able to use the UWB and non-UWB beacons together with the iOS app, and the Estimote app for Android cannot be used for the room-mapping process at all.

3.1.7 Positioning with beacons

There are multiple approaches that are used to be able to position and locate a user's whereabouts, the most common with beacons are fingerprinting, trilateration and proximity-based.

Fingerprinting is a technique where one compares the position-relevant data that we have at the moment, with recordings in a database which contains where what data is recorded at what whereabouts. Proximity-based positioning is not about precision positioning, but about determining approximate whereabouts like is he near this object. The approaches base themselves on for instance the received signal strength, to be able to estimate whereabouts.

Trilateration also need a database of where and what things are, it estimates based on the strength of the signals and what devices they are from, what possible positions are likely that the phone is. If one think of the broadcasting devices with circles around them representing how far a distance the signal travels, trilateration gives you the intersection between the circles and thus can say something about your whereabouts. Triangulation work in a similar fashion, but additionally to distance it also consider the angles of the triangles one can create between the points. Time of Arrival, and Time Difference of Arrival, which as the name states instead of basing itself on signal strength it focuses on the time. Based on the travel times of the signal, the distance can be estimated.

This kind of positioning isn't used in the project, as an actual retail store setup and testing were not conducted. However, it is important to note that different positioning techniques and filtering help the accuracy, although sometimes there might be a trade-off in speed of the estimation and the accuracy. Even with the positioning techniques and filtering, quite often it is seen that additional aid for the system is beneficial in giving higher precision. The additional aid is often some sort of sensor fusion/hybrid approach, where they use for instance not only BLE beacons, but might additionally use WiFi-signals if present and the inertial sensors on the smartphone.

3.1.8 iBeacon

iBeacon is as mentioned Apples protocol for BLE, dating back to 2013. The protocol describes what the transmitted signals should look like, and what data they should contain. Figure 3.3 shows the explanation of what the iBeacon protocol states about the ID that is broadcast and figure 3.2 shows an example of how the IDs can be used to structure the information. The images are borrowed from the 'Getting Started with iBeacon' guide by Apple (2014), which serves as a very good introduction to iBeacon. The approach in the images are of course not the only approach, there are various ways one can have the IDs represent different things. The Universally Unique Identifier (hereby UUID), the major and the minor is what typically is the most interesting part of the information the beacons broadcast in applications based on context and proximity-based functionality.

Store Location		San Francisco	Paris	London
UUID		D9B9EC1F-3925-43D0-80A9-1E39D4CEA95C		
Major		1	2	3
Minor	Clothing	10	10	10
	Housewares	20	20	20
	Automotive	30	30	30

Figure 3.2: Example of how one can structure the IDs to relate to the stores
Source: *iBeacon Guide, 2014, developer.apple.com*

Field	Size	Description
UUID	16 bytes	Application developers should define a UUID specific to their app and deployment use case.
Major	2 bytes	Further specifies a specific iBeacon and use case. For example, this could define a sub-region within a larger region defined by the UUID.
Minor	2 bytes	Allows further subdivision of region or use case, specified by the application developer.

Figure 3.3: Explanation of the intended purpose of the UUID, Major and Minor
Source: *iBeacon Guide, 2014, developer.apple.com*

Figure 3.4 shows an illustration from Estimote, which illustrates simply how the smartphone senses the ID broadcasted by a beacon and uses it to look up in a database and presents the result to the user.

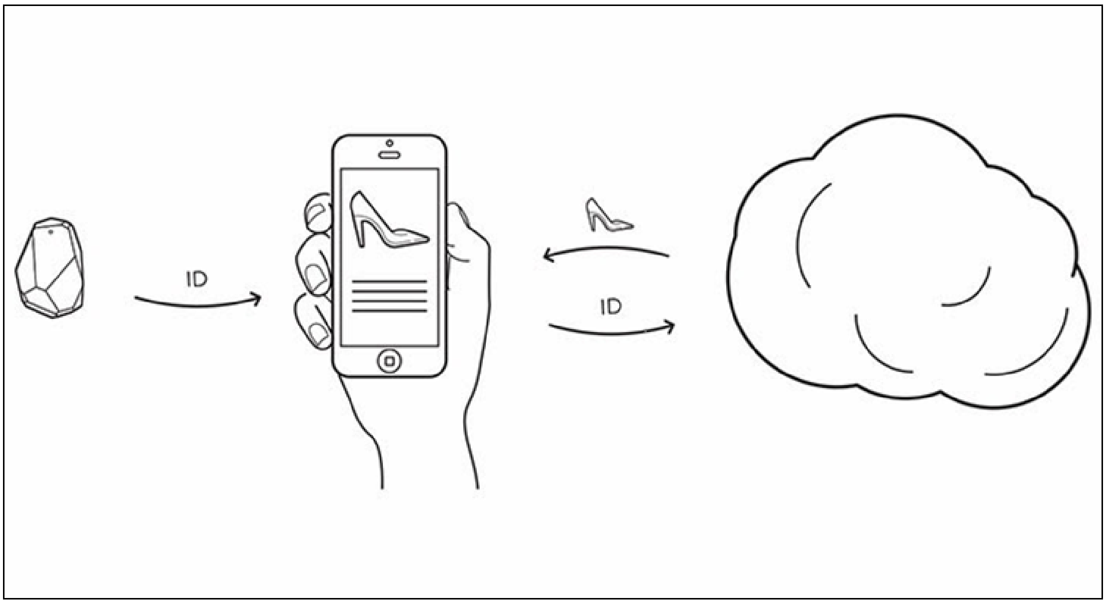


Figure 3.4: Simple illustration from Estimote of how the ID flows in such systems
Source: *Estimote, 2018, community.estimote.com*

The topic of IDs and representing data will be covered more in section 4.5 of chapter 4, but the structure that is used in the database for the artifact consists of the UUID representing the store, the majors representing sections of that store, and the minor representing specific products or product groups.

3.1.9 Eddystone

Google has its own BLE protocol called Eddystone, which is a competitor to iBeacon. Information on Eddystone is available on Google's developer-guides about Eddystone, and it explains many of the details regarding the protocol. Like how it was made to support both Android and iOS devices, that the protocol is open-source, and that the protocol allows different "payloads" to be broadcasted (Google, 2017b). It essentially means that the protocol allows transmitting of additional things to strings that represents IDs, figure 3.5 shows a simple graphic on what it is and can be used for. It opens up for functionality like changing the behavior of advertisement based on temperature inside a store, for instance show an ad for ice coffee rather than coffee if it the temperature is too hot.

Additionally, Eddystone has their "Ephemeral Identifier", which is sort of a more secure and dynamic way of working with beacons and their IDs. It is dynamic in the way that it makes the beacons change the IDs they broadcast every few minutes, so that one needs to have access to a service that can help "decrypt" the IDs in order to utilize them. It helps prevent free-riding and piggybacking of the beacons (other people utilizing your

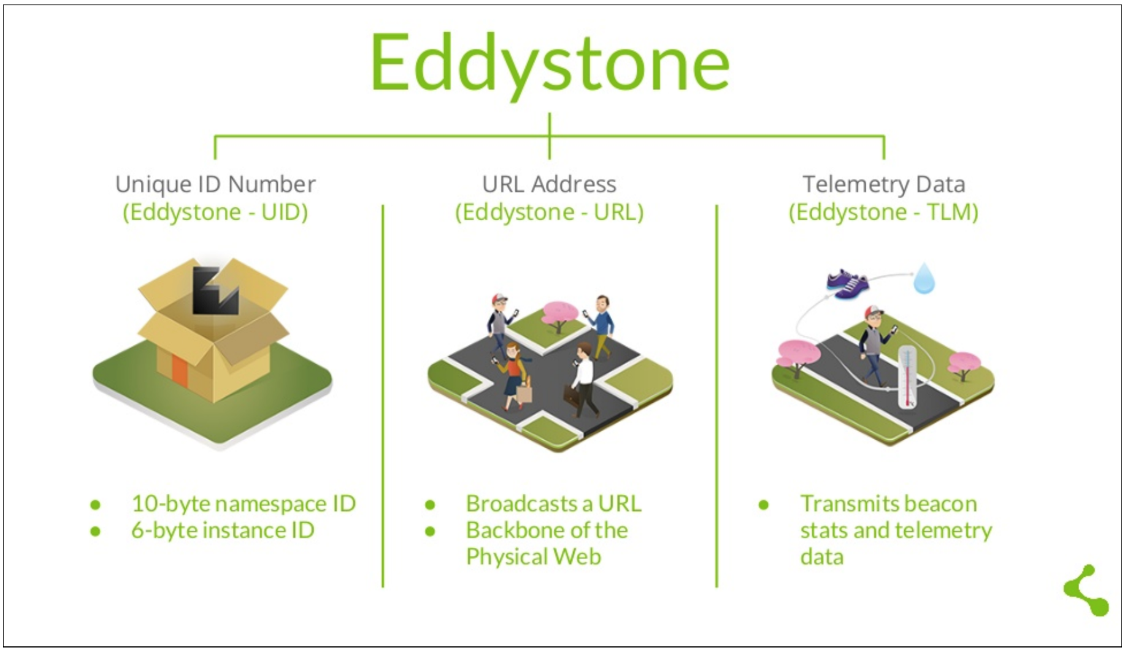


Figure 3.5: An illustration from Kontakt.io that presents the options with Eddystone
Source: *Kontakt.io, 2015, Slideshare.net*

beacons), it can help with privacy in some scenarios and it opens up for things like being able to lease out a beacon network.

3.1.10 Other protocols

Radius Networks also has a protocol called AltBeacon, which is open-source and resembles iBeacon rather than Eddystone. It is not used in the project, but Radius Network's AltBeacon Software Development Kit (hereby SDK) is however used. In the fall of 2017 another protocol was published, the GeoBeacon protocol (Tippner, 2017). As to my knowledge and understanding, GeoBeacon broadcasts BLE packets containing coordinates in the format of the Natural Area Coding System which is an alternative geocode system.

3.1.11 Ultra-wideband

UWB is also covered in this section, as some of the Estimote beacons comes with UWB technology. We will later see that UWB is a promising technology and it seems like a smart move on Estimote's behalf to offer beacons with different technologies on-board.

UWB is a radio technology, that uses radio-frequencies like many alternative technologies, the special thing about UWB is that it uses a very wide band of the radio frequencies and broadcast at very low power. To get a good initial understanding and some details of what UWB is, Intel's white paper on UWB technology from 2004 is a good place to start (Intel, 2004). In it they explain that UWB is different from conventional narrow-band radio-frequency and spread spectrum technologies, in that it uses *"an extremely wide band of RF spectrum to transmit data. It is able to transmit more data in a given period of time than the more traditional technologies."*. It operates in the frequencies between 3.1 - 10.6 GHz, each channel can consist of more than 500 MHz, and for the FCC (Federal Communcations Comission) to allow the use of such large signal bandwidths they set strict restrictions on broadcasting power of such devices. Which means that the radios must have low power consumption, and therefore UWB has low power requirements. Every UWB device can be both a sender and receiver. When describing some advantages with the UWB technology, Tsang and El-Gamal (2005) put it as following: *"...an UWB signal "behaves as noise" to other radio systems, which results in a low probability of interception and detection. Besides, an UWB signal has excellent multipath immunity and less susceptibility to interferences from other radios, due to its wide bandwidth nature."*. Two years earlier Zhuang et al. (2003) also acknowledged all these advantages but were concerned with the need for research on the technology in order to make it as good as it had potential to be.

In an article explaining differences with localization using UWB, WiFi and Bluetooth, Connell (2015) concluded with: *"For electronics designers that need very precise location measurement, accurate to 5 to 10 cm with small size and power requirements, few choices exist on the market beyond modern UWB systems. UWB is currently at a disadvantage of not being handled by today's smartphones and mobile devices, but this will likely change over the next several years. For Internet of Things devices, wearable devices, and robots, UWB offers the promise of much more location precision versus other radio systems."*. A few years later in a blog post dated the 5th of January 2017, Estimote released the news that they now had beacons that could automatically create floor plans (Estimote, 2017c). They also claimed that their beacons were the first on market that came with an UWB radio, which is what is used to create the mentioned floor plans. Later, the 25th of May they announced that the Location Beacons with UWB now were shipping (Estimote, 2017b). Mapping out a room can be done by following the steps portrayed in the article on how to do so Estimote (2017a), it involves downloading an app, placing beacons, walking around the room and then waiting for their backend to generate the mapping based on the data collected.

3.2 Alternative technologies

In this section alternative technologies to BLE beacons and UWB is briefly explained, these could be part of a system that work instead of or alongside beacons with BLE and or UWB. Additionally, some relevant concepts are mentioned, and attempts are made at clarifying some ambiguous terms.

3.2.1 Near-Field Communication

Near-Field Communication (hereby NFC) are a low range wireless communication technology, often used for payment and hassle-free pairing of devices. It is often used within ranges of less than 5 centimeter but ranges less than 20 centimeter is apparently achievable. It could for instance be in a digital shelf-label and serve you information based on the product associated with the tag. Most of us have seen NFC today as a method of payment, as many new credit cards have NFC built-in. Smartphone based NFC payment is available as technology but is not common in Norway yet.

3.2.2 Barcodes and Quick Response-codes

Barcodes, QR-codes and the likes, are technologies that are broadly known today. In stores and retail barcodes are usually seen on all products and works as an identifying string of numbers that represent a product, that can be queried from the store's database and provide information, location, price and more. These kinds of codes can be used for providing users with a simple way of getting the same and even more information. They can be used on for instance the floor as "checkpoints" that is picked up by the smartphone camera, either to calibrate where the user is, to instantiate some process or simply as an alternative/aid to a system that relies on known the user's position for some reason.

3.2.3 Wireless Fidelity

Wireless Fidelity, better known as WiFi, is a technology which we all know and love. It can be used for different purposes than making sure you are able to browse the web, one of which is indoor positioning. Arguments for using WiFi is amongst others that one can use existing infrastructure, i.e. the WiFi access points are already there. It is also connected to the electrical wiring of buildings, so there is usually low maintenance on the access points. Most modern and mainstream devices today have WiFi support, which is beneficial.

3.2.4 ZigBee

Zigbee is a low power wireless technology, which shares many of the same use cases as BLE. They are alternatives to each other in many ways, with their respective pros and cons. The focus in this thesis is on BLE, as it is supported and can be used with so many devices. Zigbee can't be used with smartphones and tablets, as these traditionally don't have the Zigbee radio and technology on-board (Hu et al., 2012).

3.2.5 Cameras

Camera surveillance and Closed-Circuit Television (CCTV), can also be used to track users and be used in the kinds of systems portrayed in this thesis. It is for instance used in Amazon Go where they with cameras and other sensors track people inside the store, for instance to see what products they pick up.

3.2.6 Ultrasonic

Ultrasonic revolves around having these speakers/beacons that transmit sound-waves that are in a range which humans can't hear, but the idea otherwise is pretty similar to the having transmitters at location X and then based on what we pick up we can pinpoint the position of the receiving device. The idea is then that the microphone on the smartphone is able to pick up the sounds.

3.2.7 Light-Fidelity and Visible Light Communication

Light-Fidelity (hereby LiFi) and Visible Light Communication (hereby VLC) are technologies that are based on light, as with WiFi an argument it might use existing infrastructure (lamps), but one does although need to buy new bulbs that come with the technology. There is also maintenance to be done, although with LED bulbs the maintenance should be very manageable. Most stores have good lighting in order for the customers to better see the products, so there often exists a good infrastructure. It works by "blinking"/flickering the lights at speeds and levels humans don't notice, but the sensors and the camera on the smartphone potentially can. Normally one might think of human-visible light, but infrared and ultraviolet which are invisible to humans can also be used.

3.2.8 Inertial sensors

Inertial sensors in this case refers to the built-in sensors in the smartphone, which we can use to estimate where the smartphone have moved. It is often seen as an aiding tool in navigation and positioning systems, as a supplement to the main system. It revolves around having the accelerometer detect motion and steps, gyroscope notice rotation, magnetometers which can tell us direction, and other sensors that can be used to give related information.

3.2.9 Global Positioning System and Global Navigation Satellite System

The GPS is a Global Navigation Satellite System (hereby GNSS) and is widely known today, and is used for navigation, positioning, etc. Our smartphones can help us navigate, many cars often have the technology included these days. The issue with the technology is that it does not work well inside, where the signals from the satellites can't reach the receivers that we have with us in the phones and cars. The fact that GPS/GNSS is not suitable for indoor use is the reason the previously mentioned technologies are investigated and looked at in terms of positioning and navigation.

3.2.10 Indoor Messaging System

Indoor Messaging System (hereby IMES) is a GPS/GNSS-IMES, think in terms of beacons and such advertising devices. Except that instead of having Bluetooth, WiFi, LiFi or sound, it advertises the same signals that we get from the GPS/GNSS. What is described is devices that broadcast the same signals, but with some additional information like floor levels/elevation. The powerful thing about this is that the GPS/GNSS receiving sensors in the phone could be re-used. Moving from the outside and getting the signals from the satellites, to inside where the same signals are provided from "beacons" instead could be a smooth transition. It would also allow for easy integration with Map Services that already use the technology, which they all do.

3.3 Term disambiguation

In this section, clarification and disambiguations are attempted at terms and words that often are mixed up and used interchangeably, and terms where it felt needed.

3.3.1 Sensor fusion/hybrid systems

As things are today, sensor fusion and hybrid systems do in many cases seem like the optimal way to go for the systems that is portrayed in this thesis. Meaning simply that one type of technology itself might not be good enough to achieve what we'd like, of course it completely depends on the requirements. Examples of a hybrid system are WiFi and BLE based systems, that maybe also use data from inertial sensors in the smartphone. Often the systems are seen together with software-based solutions like filtering and fingerprinting to get better accuracy. The Estimote BLE+UWB beacons are an example of how one can have multiple technologies in one device, to more easily realize hybrid systems.

3.3.2 Indoor Positioning Systems and Real-Time Location Systems

Harrop and Das (2014) explains an Indoor Positioning System (hereby IPS) as primarily concerning location-based services on mobile phone where GPS does not work, and Real-Time Location Systems (hereby RTLS) primarily concerning locating people and things securely at a distance.

Wiig (2010) stated that IPS is a type of RTLS, and that a RTLS revolves around locating or tracking people, assets or objects in real-time.

While these two terms are closely related, my general understanding of the terms after reading literature and browsing the industry is that IPS cover the indoors, where traditional positioning methods are not available. And the term IPS is thought of in most use cases as the indoor version of GPS, which revolves about being able to assist users in navigation and being able to position them and present their position to them in the environment. It seems the term RTLS is more targeted to industrial applications like manufacturing plants, storage/warehouse optimization and other uses that the average consumers don't really see. An IPS is something the customers might directly use and benefit from, RTLS might be more behind the scenes of process optimization and analytics.

3.3.3 Location and position

Holger and Willig (2006) wrote *"While these two concepts are different, there is no consistent nomenclature in the literature - position and location are often used interchangeably. The tendency is to use "location" as the more general term. We have to rely on context to distinguish between these two contexts."*. Holger and Willig (2006) also write that they distinguish position and location by what they call "physical position" with values that is numeric coordinates, and "symbolic location" with symbolic values like "living room" or "office 123 in building 4".

The issue of distinguishing the terms has been posted on `stackexchange.com` as well, both in the domain of robotics (Stackexchange.com, 2015a) and GIS (geographical information systems) (Stackexchange.com, 2015b). Both original posters mention that the terms are often used interchangeably, the general consensus amongst the responders are that position is the XYZ, and location is the place. So, Oslo is a location, and its position is the coordinates 59°55′0"N 10°44′0′"E. A location is more context centered and has a semantic meaning, while a position is a value that is meant to represent somewhere in a coordinate system.

Generally, when the terms positioning and localization is used, it is about being able to tell where an object is, whether in terms of specific coordinates, an area or contextualized environment. With common sense and taking into consideration the context where the word is used, hopefully confusion is avoided.

3.3.4 Micro-location and micro-positioning

The term micro-location is somewhat ambiguous, although it is used often as being about proximity in for instance a room *"...determining the location of something within a specific and limited area like the floor of a building."* (Godoy, 2017), and *"For a majority of the indoor location or micro-location type scenarios, proximity is more in line with what your probably gonna want than true positional location."* (Sterling and Hegenderfer, 2014).

Zafari et al. (2016) has what seems as a different understanding *"Micro-location is the process of locating any entity with high accuracy (possibly in centimeters)..."* and, *"Tracking a user with high accuracy is known as Micro-Location."* (Zafari and Papapanagiotou, 2015). In light of the clarification of location versus position, even though I have not seen it used in this context, I argue that for their definition a more suitable term would be micro-positioning.

Some of the features presented in the concepts and artifact of this thesis, rely on having micro-location, some on micro-position. Micro-location is about whereabouts, like being nearby an object or in an area. Micro-position is being at a specific point, and a position is a value that states something about where exactly the point is.

3.3.5 Digitization and digitalization

Merriam-Webster's and Collin's online dictionaries explains digitization as turning something, like data, information and images into something digital that is easily read by a computer. And they both define digitalization as digitization, not differing between the semantics of the words.

Gartner's online IT-glossary defines digitalization as: *"Digitalization is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business."*. It sees digitization as the process of changing/converting analog things into digital form, which generally seemed to be agreed upon.

My understanding of the terms are:

Digitization is the process of converting information, data, objects and things into digital and computer-readable formats, being able to represent non-digital elements in a digital environment.

Digitalization is using digitized data, elements and technology, with the goal of optimizing processes, workflows and the likes, and to provide value-producing opportunities.

Although this thesis covers both digitalization and digitization, the title of this thesis use the term digitalization. The reason is that digitalization often includes and need digitization, while digitization can be done without further usage of the digitized data. If I only were to look at the way of best representing the non-digital elements in the stores, without considering usages, digitization would be the more appropriate term. The retail stores are digitalized, and several aspects and elements within the store is digitized.

As an example, in the context of this thesis, concepts like the CloudQueue is a digitalization of the traditional ticket-based queue system. The digitalization of the queue relies on the digitization of the elements of the queue, the people in it, their position in the queue and their actual positions in the store.

3.4 Relevant work and technology in the industry

Covered in this section is a presentation of the industry and what kind of relevant projects and technologies were found. Many of the notable companies that do things related to the artifact will be covered, but the list is not exhaustive.

3.4.1 Indoor maps

A problem with navigation indoors isn't just positioning the user, we have to know where things are and where to go, we need indoor maps.

IndoorAtlas, a Finnish startup, provide services for creating Indoor Maps. They offer a SDK that people can incorporate into their systems, and it integrates with real-world maps. The user can add architectural plans on top of the real-world buildings, as seen in figure 3.6, which solves the scaling of the venue in relation to the map. IndoorAtlas uses fingerprinting and a hybrid solution with information from the magnetometer(compass), as well as inertial sensors from the smartphone, and if available WiFi and Bluetooth.

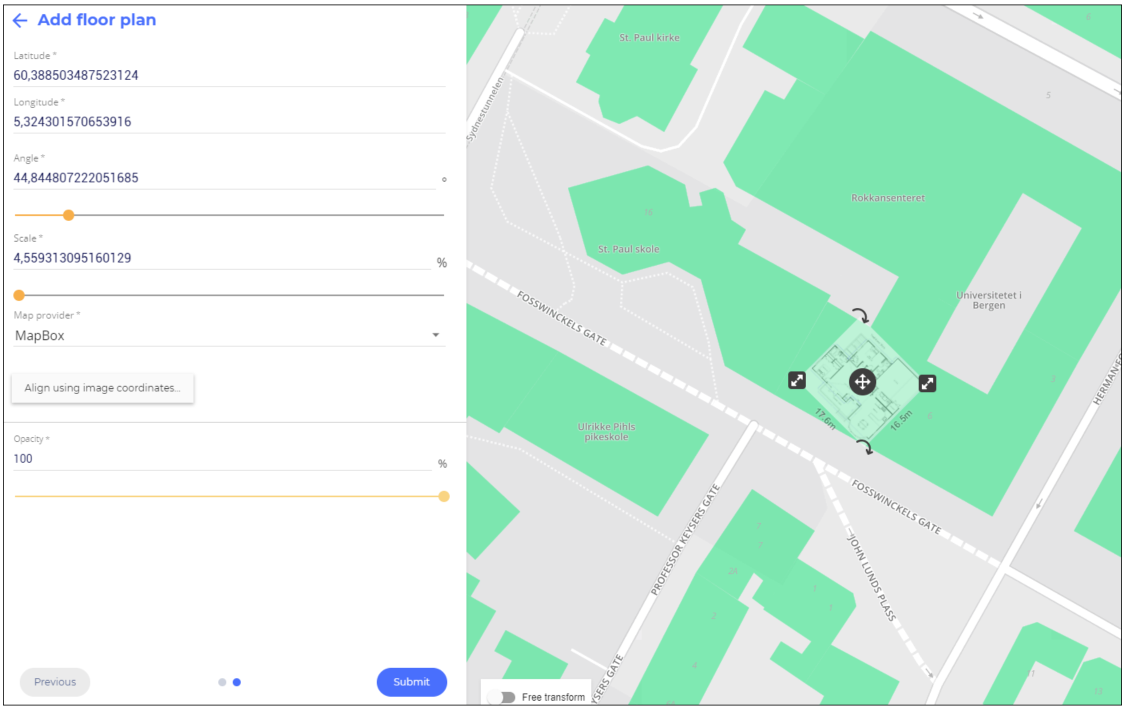


Figure 3.6: Indoor Atlas' tool for placing architectural plans on top of a real map

SteerPath is a company that provides many of the same features as IndoorAtlas, but they base it all on BLE beacons. There are several features in their SDK that is relevant to the artifact of this thesis, like wayfinding and positioning. The feature of placing architectural plans on top of an actual map is also offered.

Microsoft PathGuide is a bit different and deal only with navigation and is about following paths they call "traces". A trace has to be manually recorded, and consists of images, text and sounds which describes or shows the next step of the trace. Once a trace is being recorded, the system also collect data from the inertial sensors of the smartphone, such as steps taken, how many turns has been made and if there is any change in floor. This solution offers descriptions of how to get the users to their destination from point A-B. The system presents the descriptions for each part of the path accordingly as the user gradually comes close to the same amount of motion and steps as the creator of the trace did.

InMapz is a platform for indoor/venue navigation. It comes in the form of apps for devices that run Android and iOS, and they provide maps for venues like malls, casinos, airports, parks and more. InMapz has concepts relevant to the artifact like letting the user search for products in stores, and helping the user find the products, although no signs of those features were found in the app. Other relevant concepts they mention are advertisement, customer notifications and analytics.

Meridian is a service that offer solutions for indoor maps, providing an SDK for developers that can be used for indoor navigation, proximity-aware information and asset tracking. It also has an app-maker feature that customers can use to integrate their services.

Micello provide navigation and the mapping of spaces onto real-world maps and can assist with geofencing and advertisement. In January 2018, they were acquired by HERE Technologies (Lunden, 2018). HERE technologies are one of the larger map providers in company with Google and Apple.

Mazemap is a Norwegian company that specializes in indoor maps and navigation of large buildings, it shares some similarities to the artifact of the thesis. When a venue is mapped out for MazeMap, MazeMap can provide indoor navigation and positioning, and the client is free to use whatever indoor position enabling technology they would like. It is similar to the indoor maps we have seen from Indoor Atlas, and will see from Google, Apple in terms of navigation and managing floor levels, floor plans etc. MazeMap has a CMS, where the client can edit details about their venues. They have an own section on their web-page on "Automatic Updates" where they state that they are aware of the fact that floor plans and buildings change, and that their system is built to be easy to update. However, they also state that they do structural updates quarterly (or more frequently if needed), which suggests that they need to be involved in the updates. Which could be a hassle, if there are many clients with venues that frequently change.

3.4.2 SLAM/Fingerprinting

Indoo.rs specialize in indoor positioning, analytics and asset tracking. Indoo.rs have solutions based on SLAM (hereby Simultaneous Localization and Mapping), their SLAM Engine, SLAM Crowd Engine and SLAM Crowd Learning. The concepts are intriguing and certainly doable from a technological point of view. Their SLAM Engine is a technique (a better technique according to them) of generating a radio map for a location, as an alternative to normal fingerprinting. Crowd Engine is about crowdsourcing the data from people walking in the venue, and Crowd Learning about applying machine learning to the data. Less tedious mapping needed, with better result, and the possibility of dynamically adapting the map to changes made sounds promising. There are privacy concerns, and potentially vulnerability to sabotage, but if solved there are great potential.

3.4.3 Indoor Positioning Systems/Real Time Location Systems

Senion offers an IPS with various features that are relevant, like contextualized and personalized advertisement, indoor wayfinding, analytics for retail and even finding your parked car. They have a concept called Smart Offices, where they analyze what rooms are being used, making it is easy to find a vacant room. It can also help track down co-workers on the premises, by having an app and detecting presence in rooms.

Point inside have solutions that incorporates many of the concepts of the artifact. They can assist in the creation of digital store maps and routes to product, searching for products in the local stores inventory and helping the user navigate to them. Other concepts they do are marketing and advertisement like customized deals and recommendations for the customers, and analytics which enables better decisions making. The better decisions are powered by giving the retail store better insight and more information about their customers and what goes on in the store.

Sewio has some very interesting technology to show, although not as concerned with BLE they do have some devices similar to beacons. One of which is what they call an UWB sniffer, which they use for RTLS for industry, retail and sports. In sports the idea seems to be that one would collect vast amounts of data from whatever game is being played. Then one utilizes the data to be able to say something about for instance actual events and movements of the participants. For retail it is all about analytics like being able to look at movements in the store and gathering all the data that can tell us a lot about what is going on in that store. An example of Sewio's RTLSStudio which demonstrate how the system looks for a store can be seen in figure 3.7. For warehouses and storages, it revolves a lot around analytics and figuring out the efficiency of different processes and whether or not thing run as optimal as they should. By having these kinds of systems, one can use some of the same technology to also make the realization of indoor navigation simpler.

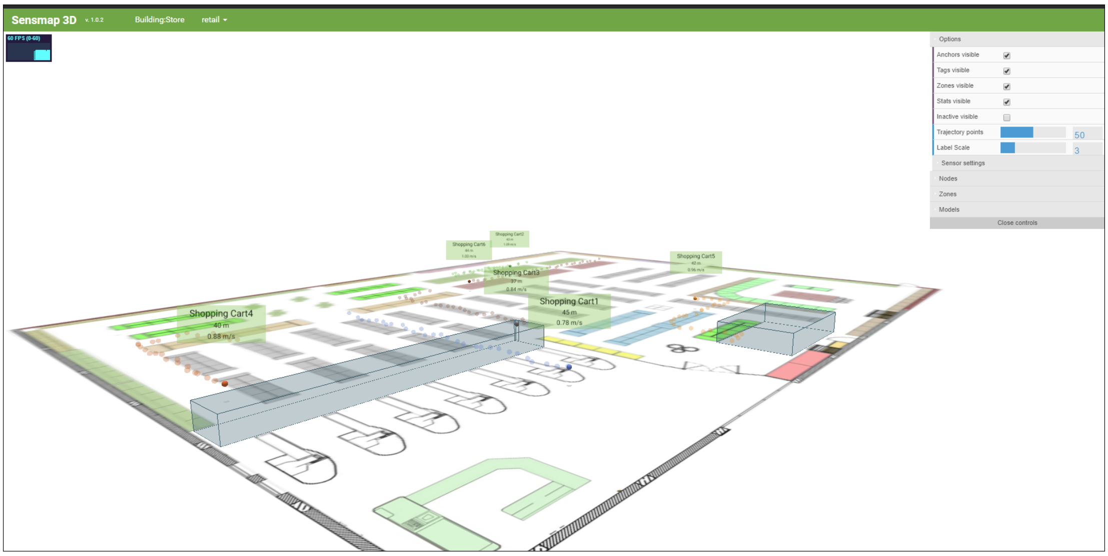


Figure 3.7: Sewio's solution shows a real-time overview in a store with positions of the cart

PikVu is an an indoor navigation system that uses artificial reality (AR) glasses, showing the users where to go to pick up the next item. PikVu is targeted at storages and warehouses, incorporated with the client's system it is able to assist in the process of finding and picking up the right products and getting them shipped to their customers. The idea here is then to make the processes more efficient through assistance and analytics. They use Bluetooth and WiFi as the means to pinpoint the person to be navigated and the products.

Onyx Beacon offered both beacons and software, their 'Tracko' system included a RTLS, which shares similarities with Sewio's. It also consisted of a mobile app and CMS, until Onyx Beacon discontinued its hardware and services in 2018. Although more targeted at logistics, the Tracko system shares similarities to the artifact in terms of being able to have a system of locations of products and being able to navigate to them using an app.

3.4.4 Beacon providers

Infsoft is a German company that delivers a system, with their own beacons, for indoor navigation, positioning, analytics and tracking. They utilize radio-frequency identification (hereby RFID), BLE, WiFi, UWB and camera systems.

BlooLoc offer beacons for indoor positioning and applications, they utilize sensor fusion and provide software for beacon management. They provide a SDK for the users, and work against fields like retail, museums, hospitals and so forth.

Aruba is a company that focuses on mobile, IoT, cloud and networks. They do many different things within the respective domains, and offer WiFi access points, BLE beacons and a combination of both. Systems that include beacons, software, hardware, CMS is also something they provide. They also have indoor maps and navigation for different venues, and seem to think that letting the users choose whether or not they want to opt-in is the way to go when it comes to solving the privacy issues.

Accent systems mainly deal with narrowband wireless devices for IoT (allowing IoT devices communicate through LTE-bands), they develop and produce their devices themselves and do consulting. They have a new beacon coming up, with seven Bluetooth directional antennas, which they market towards what they call indoor- and micro-location.

Kontakt.io provides their own beacons, and system for managing their beacons. They also provide SDK's and an Application Programming Interface (hereby API) which developers can utilize and incorporate into their own platforms, it is one of the companies that resembles Estimote the most in terms of what they can offer and what they are doing.

GoIndoor is a navigation technology provided by a company named OnYourMap, they are working with relevant concepts like indoor maps, navigation, routing and geocoding. GoIndoor also provides a system where one can view data, manage locations and beacons. A SDK and API is offered, and so is packages with beacons, software and tools needed for integration with their system.

Radius Networks provide beacons and SDKs that can be used with them. Radius Networks also has an own protocol for beacon communication named AltBeacon, the AltBeacon SDK is used with the artifact in this thesis.

Estimote have already been covered in subsection 3.1.5.

3.4.5 Analytics and marketing

Bluedot Innovation is a company that work with advertisement, location marketing and analytics, providing its customers with a solution that cover both the in- and outdoors, with what they claim to be superior accuracy. Outside they have a technology which they called Geoline which are used to trigger different actions, the technology is proprietary but has similarities and resembles geofencing in some aspects. They do seem to take privacy concerns into account, with claims of not collecting personal information about end-users and anonymization of their data multiple times.

Locatify promote and offer the use of heatmaps and user analytics to make better and more informed business decisions. They have a treasure hunt game based on geofencing and smart guide for tourism, and can help their customers build their own app. They have a CMS which supports many artifact relevant features like different positioning technologies, navigation, offline maps, geofencing, artificial reality and more.

3.4.6 Google - Indoor

Google's Indoor Maps was in the Fall of 2017 in beta and not available in Norway, therefore it was not considered an option for the artifact. However, as of January 2018 it became available in several countries including Norway. Google have been working on this for many years, early demonstrations could be seen on YouTube already in 2011 (PhoneArena, 2011). In 2013 it was a topic at Google's annual conference Google I/O. The way Google maps out the indoor spaces are similar to what we saw with IndoorAtlas, the building/venue owner submit floor plans through a tool where he has to click and drag the floor plan over the according building on the map. This way one knows that the scales will be accurate, given that the floor plans are accurate. What Google then does is that they go in and trace the mapping, and markup points of interest (hereby POI). This enables navigation to different places within the venue. All of this is demonstrated on Google's YouTube video from the Google I/O 2013 conference, on the part about Indoor Maps (Kadous and Peterson, 2013). One of the struggles they presented, which still exists as of today, is accurate positioning inside these buildings. A solution is needed that is easy to setup, easy to maintain, is not too invasive, not too expensive and it must be compatible with most devices. Finding such a solution have proven to be quite the challenge, one of the less known technologies that might help to solve it is LiFi. Figure 3.8 illustrates Martyn James' and Google's patent of how one can use the LiFi technology for indoor positioning and navigation (James, 2017).

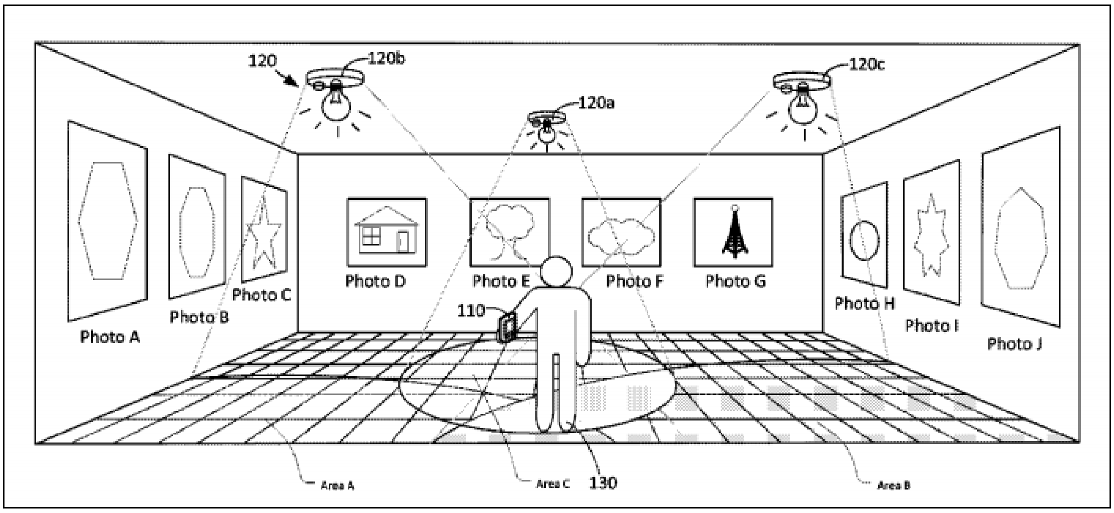


Figure 3.8: Image from Google's patent on an IPS using LiFi technology

In Google's documentation and guides for their Maps API, they mention that there are two normal ways to utilize Indoor Maps. The first is as mentioned, uploading floor plans, and in the end making the mapping of the venue publicly available for everyone. The second is adding the same kind of floor plan overlay, but in your own app, without any submissions to Google. The second will then only be available to the users of that specific app (Google, 2017c). A possible solution to the problem regarding how some venues like stores change internally quite often, and therefore the mapping needs to change as well, could perhaps be solved by combining a public Google Maps indoor mapping with an own overlay from the venue.

As a way of assisting Google with the accuracy of the indoor positioning and navigation, they offer an app called Google Maps Floor Plan Marker. In which one gathers data by following instructions, which Google then uses to improve accuracy for the venue. Assisting Google making a fingerprint of the venue, in other words. It is similar to what IndoorAtlas also provides, but it is uncertain what exactly is collected from Google's app. IndoorAtlas gathers geomagnetic data, Bluetooth-signals, WiFi-signals, and various data from the phones inertial sensors for its fingerprinting of a location (IndoorAtlas, 2017). The app might benefit from similar concepts to Indoo.rs' SLAM technology (crowdsourcing the needed data in the background).

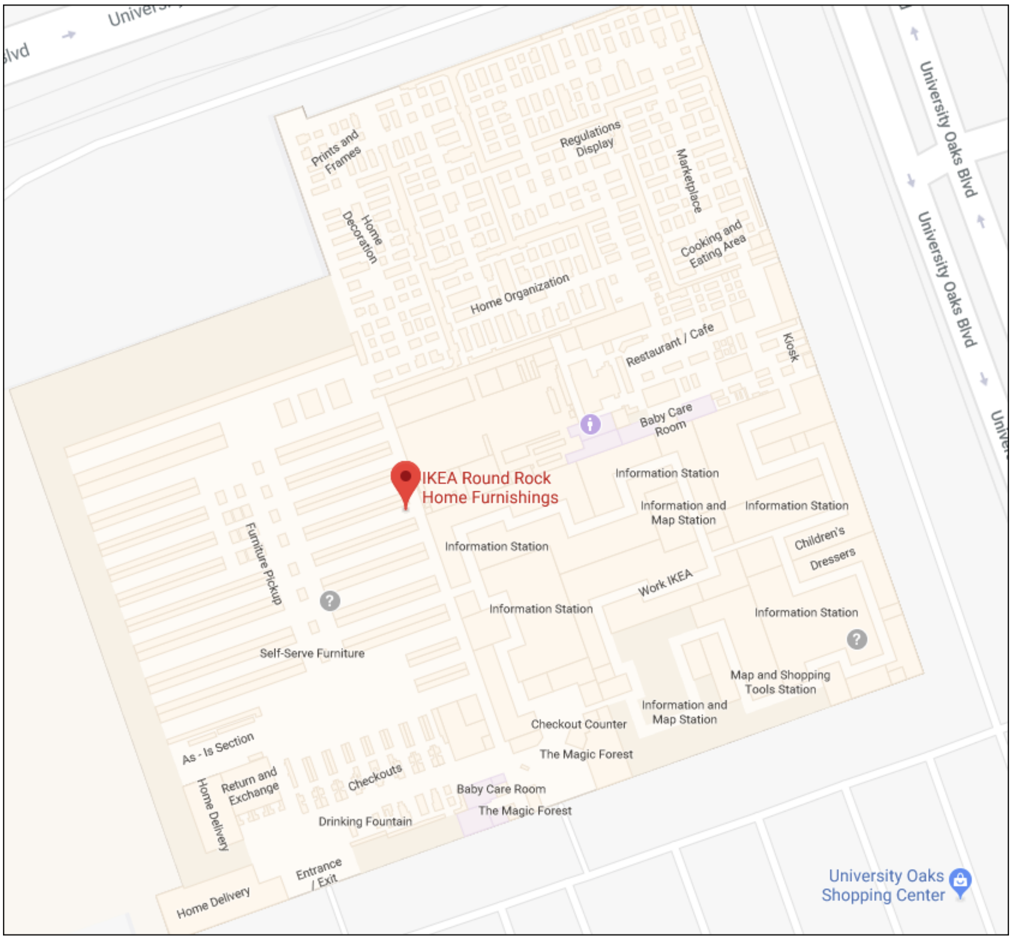


Figure 3.9: Ikea Round Rock on Google Maps with the indoor map of the building

Figure 3.9 shows Ikea Round Rock in Texas on Google Maps, which demonstrates the

Indoor Maps feature. The building has an indoor map with the shelves, different areas and points of interest. As mentioned most stores are dynamic, things move around and change every now and then. It is not apparent what Google's solution to that problem is, but if the processing of these indoor map submissions requires human interaction from Google's employees it could become quite a demanding task to keep up as the service grows. Figure 3.10 shows how the indoor navigation utilizes the already existing technology in Google Maps, and it lays what seems to be a solid foundation to build onto.

An approach to the problem of positioning inside these buildings are the Google Maps Floor Plan Marker. As of May 2018, if one needs to change something in the indoor map one has to involve Google. Getting details about how the updates and changes in floor plans works was easier said than done, but one can assume that Google needs to go in and edit the files that represents the building's floor plan. This seems less than optimal; a solution where certain people are given access to change the floor plan that is displayed on Google maps might be an alternative. For instance, the store manager, department leaders and other trusted individuals at Ikea Red Rock would be able to change details for their store. In March 2018 Google released details for the new version of Android, which enables support for indoor-navigation with WiFi round-trip-time (RTT) which comes with the IEEE 802.11mc standard (Google, 2018a). This enables developers to access an RTT API which can be used for estimating the position in indoor locations.

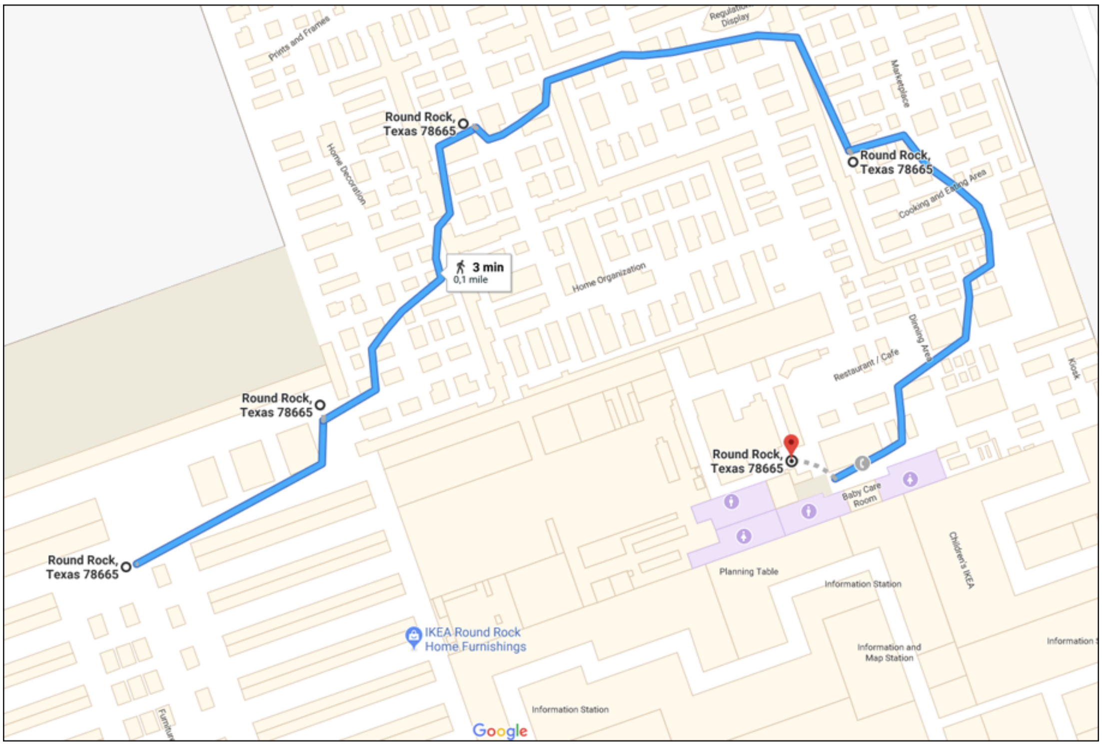


Figure 3.10: Indoor point-to-point navigation at Ikea Round Rock on Google Maps

3.4.7 Apple - Indoor

In the end of 2017, TechCrunch published an article about Apple's release of iOS 11 and an exciting feature that came with it. In iOS you have Apple Maps (as an alternative to Google Maps), which now also featured several indoor-venues like airports (Heater, 2017). It shares a lot of similarities with the other maps, but Apple Maps Indoor and Google's indoor maps really resemble each other. From the way you handle floor changes on the upper right corner, to the way you navigate, view the locations in 3D and how they all exist within the already well-known interfaces they each provide. As of May 2018, it seems Apple's indoor maps consists mainly of some airports and shopping malls, however it seems their list of venues with indoor maps are increasing.

Apple released an app called Indoor Survey in 2015, according to Campbell (2015). It seems to be similar to the Google Maps Floor Plan Marker app, in that users can use it to map out information about their venues. It probably incorporates some of the technology the Apple acquired WiFiSLAM was working on, what WiFiSLAM was working on was described by Panzarino (2013), and this supports the suggestion that the technology might be incorporated into their Indoor Survey app. They seem to do the fingerprinting like we have seen elsewhere in terms of gathering various data from the phone's inertial sensors, WiFi and likely other technologies. Additionally, they apply filtering, do predictions and run different algorithms to best determine where the user have been, where he is and where he is going.

Indoor Survey almost sounds like what one could think were an app that gave the user credits in App Store, as a kind of payment for the service of using their data to help map out different venues. This could be something of a combination between survey app and crowdsourcing data in order to improve accuracy on indoor maps. Condliffe (2015) also seem to think that crowdsourcing might be a factor in the app.

3.4.8 Amazon Go

Amazon Go is also worth mentioning, although it doesn't specifically relate to indoor navigation, product finding and that category of features. It does however relate very in terms of sharing the idea that physical stores can be improved and be better at adopting technology. Amazon Go makes the customer more self-reliant, and the stores enable the customers to have a faster and more pleasant shopping experience. Amazon Go lets the customer go inside the store and identify themselves with their Amazon account by scanning a code in the store entry-points, then they can grab whatever products they would like, when they have grabbed all they want they can simply leave. Amazon could probably have utilized beacons as an alternative to having the customers put their phone on a device that scans their phone's screen for a code. Amazon utilizes sensors, microphones, camera surveillance and more to be able to track who grabbed what, from where and how much (Puerini et al., 2014). When the customer leave, the price of the products they grabbed automatically get charged to their Amazon account. Although there are no cashiers, they do have staff, who can assist the customers if there is trouble, and help keeping the shelves filled and the store tidy. It does offer a queue-free and simple shopping experience, but the customer provide Amazon with data as they monitor and track everything that goes on in the store. It might seem that especially the younger generations think the trade-off is worthwhile (Boyle, 2016).

Puerini et al. (2014) filed the patent which contains figure 3.11, which shows the patent for some of the technology that Amazon uses for tracking and detecting what goes in the store. Whether or not Amazon will use the data for "physical-to-online retargeting" are unknown, as answered by Amazon Go vice CTO Dilip Kumar (Bishop, 2018). It does not seem that far-fetched, physical-to-online and online-to-physical remarketing and retargeting is one of the approaches retail chains can use to attempt to improve their sales. Retargeting is traditionally done with cookies in the web browser, to for instance show a person ads for a product he have previously viewed. The contextualization and digitalization of physical stores could open up for the retargeting using more than web browser browsed data.

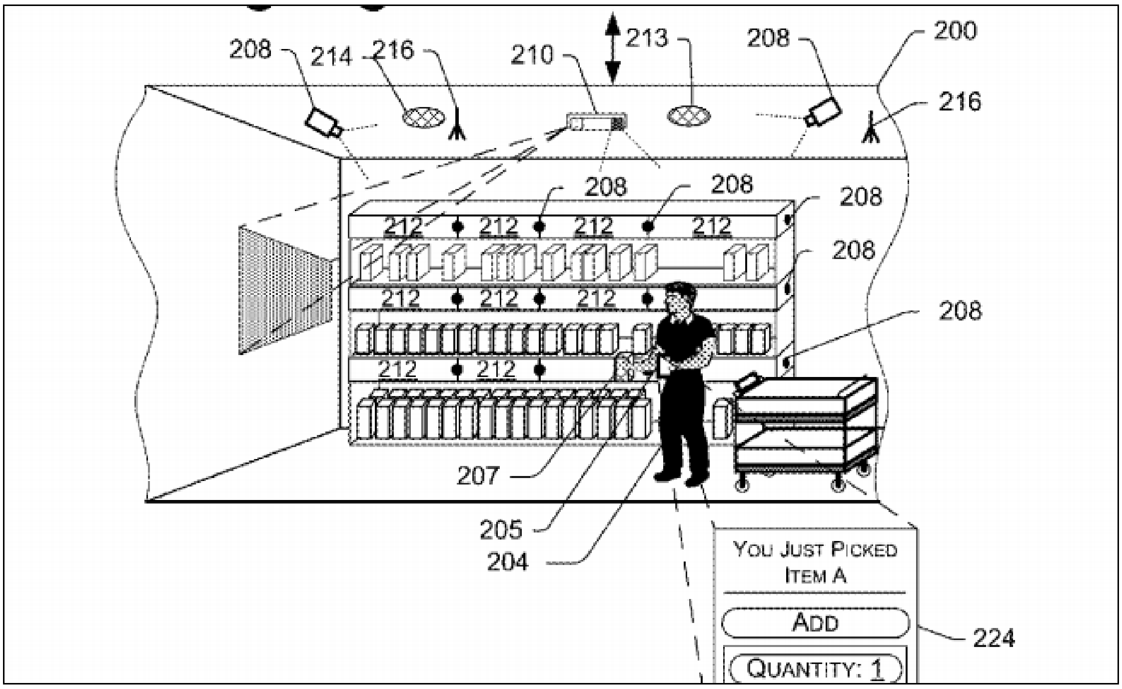


Figure 3.11: Excerpt of the original image in Amazon's patent, illustrating the idea

3.4.9 Qualcomm Patent

Graube et al. (2013) filed a patent on the behalf of Qualcomm Technologies International, concerning setup of a beacon network in retail environments. This is highly relevant to the artifact, covering aspects like where to place the beacons and how to set up the "network" of beacons. It mentions technologies like IR, ultrasonic, NFC, WiFi and Bluetooth as potential devices that can be used.

A shared concept in the patent and the artifact, is the ability to see what products are nearby: *"With the proliferation of sensors and mobile listening devices, it may be possible for users, employing mobile listening devices, to gather information related to products in an indoor area based on the ability of the listening device to unambiguously receive data from one of the transponders located in the indoor area."*.

Generally, the patent brings up many of the difficulties of working within the retail environment, like how one can have a beacon be associated with products in the vicinity, the artifact includes an approach to this. It does this by having the identifiers transmitted by the beacons be stored in a database with relating product information of what products are in vicinity of that beacon.

This patent is one of the most relevant documents that I have found in terms of similarity to the artifact. It covers many, but not all parts of the artifact. It does not contain details of navigation and positioning, but it does cover for instance how one can use proximity, barcodes, QR codes and image recognition together with a database in order to provide information about products to customers. And it covers advertisement and data collection for different use cases. They for instance suggest that one can have indoor map details and planograms stored in databases, which can be used to show the customer exactly what product it is he is looking for. Graube et al. (2013) explains the concept of a planogram: *"A planogram is a layout of a retail venue that provides a diagram or model that indicates the placement of retail products on shelves."*. They do suggest possibilities like using inertial sensors like a phones accelerometer in order to gather information on movement to add onto a fingerprinting database, which can help determine proximity to the radio-frequency transmitters. They also mention that low energy devices running on small batteries can be utilized, as well as devices that use larger batteries or even are connected to the store's electrical network. The paper also addresses different approaches like how one can have the beacons represent different things, it can be a location, a shelf, a product group, a specific product or something else. It also proposes that a CMS should provide the staff with easy configuration, setup and adaption of the network. They recognize that retail stores change ever now and then, so that it is of utter importance that the system is easy to update and manage. They also seem keen on having a sort of admin-device which for instance can be used to "pair" a beacon with a product/product group, or whatever the data structure is being used. It could for instance be an app on a smartphone or a unique device that could be used for this, but it would serve as an extension and tool for the CMS. Generally, the patent covers much of the details that one would find in applications such like the artifact.

3.4.10 Electronic Shelf Labels

Accuracy, cost, maintenance, infrastructure is some of the keywords that is looked at when it comes to evaluating different approaches to find the best solution for IPSs. WiFi has the advantage of often being able to utilize existing infrastructure in WiFi access points, LiFi can also utilizes some existing infrastructure, but that is an advantage which BLE beacons seem to lack.

An idea came to mind for a beacon network in a retail store, which is the focus of this thesis, that also uses existing infrastructure. Or, if a new infrastructure needs to be installed, it can be a 2 for the price of 1, like how you'd get both light bulbs and lamps if you want to install a LiFi based system.

It is a system of devices that work on batteries, but could be integrated into the electrical grid of the store. The system could potentially be communicating in a mesh network, and could offer information in text, scanable codes and pictures. Electronic shelf labels (hereby ESL), that also incorporate radio-frequency transmission and serve an additional role as a beacon. Many retail stores are already implementing ESL systems, as they see many benefits with the technology. Like remote control of the labels through the company headquarters, dynamic and automatic price changes, freeing up the staffs time, serving the customer better and potentially personalized information on the ESLs and so on. Adding another benefit would hopefully incentivize the stores even more to invest in such systems, and ESLs that comes with technologies like NFC, Zigbee, WiFi and BLE do already exist. In the remainder of this section we will look at four vendors that were found interesting that are on the market today.

Solum ESL provides ESLs and the system around it, like access points that update the prices to the ESL using the ZigBee protocol. The assignment of ESL to product happens with a smartphone which assigns the labels to products in the database, so that the prices can be automatically and easily updated. Most of their labels seem to have a battery lifetime of around five years in room temperature, one of the reasons for the "long" lifetime is that their displays use e-paper and e-ink which have very low power consumption.

Displaydata has ESLs that come with BLE and NFC. The ESLs can serve as BLE beacons as an addition to their primary role, which Displaydata suggests can be used for "targeted, relevant and timely promos to smartphones based on their location in store" (Displaydata, 2016). Their ESLs are able to notify of its battery status and temperature, so one can monitor the ESL's health. They also have WiFi access points which communicate with the ESLs in order to update prices and information on the labels.

Ses-imagotag also uses e-ink displays and have ESLs that come with NFC. They state on their website that they offer support for multiple radio frequency communications like WiFi, BLE and NFC. They have access points for connecting to the ESLs, and a CMS called 'Jeegy' where they can change the ESLs, look at statistics and do all the behind-the-scenes things related to the system. They have a concept which they Shopper Connectivity, where they have the option for the customers to access information on the products through either search, scanning of QR code on the label or by holding the phone against the label. NFC is the technology that enables holding the phone against the label in order to get the product information, one of the benefits are that the short range ensures that if the customer has chosen the right ESL, then he undoubtedly will get information for the right product. Another interesting product they have is their 'Findbox' which is a box where one can put items and products, and it will scan the barcode or analyze the image of the item, and then help the user find the appropriate product they want. As the box is integrated with the store's system, it can make the ESLs blink its LEDs (if it has LEDs), which makes it easy for the customer to detect. The Findbox would be a great concept as part of an app like the artifact, however the physical box doesn't seem necessary, the same can be done with the phone's camera. In that scenario it is although great as there are many alternatives that look similar, and they are all close to each other which makes it hard to find the right one. The idea of blinking LEDs in the ESL of the product the customer is looking for is elegant, and with an IPS one can trigger the LED to blink for instance when the customer is less than five meters away.

Pricer is another provider, which has a unique approach in comparison to the others mentioned, they have a system that utilize IR-light as the means of the ESL configuration (updating prices, etc.). They offer the usual CMS and platform for maintenance and configuration of the system, and they provide access points which can send price information to the ESLs. They offer an API which their clients can use with their own system and apps, and the platform supports BLE beacons. Their system supports localization of the labels using IR light, and localization of persons using BLE beacons, they do this by having BLE technology inside the IR transceivers. They also offer indoor navigation, IPS and targeted promotions and geofencing. Pricer can also offer ESLs with blinking LEDs, NFC enabled product information presenting to customers, they call this Shelf Interactivity. Pricer also has a concept they call Shopper Guidance, which includes visit planning for the customers and real time guidance for optimal routes. They state that the products are available in the cloud so that the customers can create shopping-lists in forehand, this arguably would be optimal as a part of the store's existing online version. After a customer has created their cart with all the products they are interested in at the online store, they could be presented with three final actions; Check-out (pay now and get the products delivered), Click&Collect (get the products packed and ready at the store) and Add To Shopping-list (for in-store navigation and guidance). They assist with in-store maps, and have their own system for maintenance, creation and configuration for these maps. This allows for in-store geofencing (dividing the store into section and doing different actions based on what section the customer enters). They offer different ESLs, with e-paper and LCD screens, two-way communication solutions between ESLs and APs, replaceable batteries and long lifetime labels (up to 10 years on some). Many of these concepts are illustrated and explained further in their 'Shelf-Edge Digital Solutions' brochure (Pricer, 2017).

This section has not contained an exhaustive list, but it does grant a quick overview over what is going on in the "industry", and present some companies, concepts and products that are relevant to the artifact of this thesis.

Many companies focus on navigation of large buildings like shopping malls, and although that could be a part of systems like the artifact, the focus is on assisting the customer in a store. For instance, helping the customer find product at Ikea, in a manner that resembles the delightfulness that blue-dot navigation can offer.

3.5 Relevant work and research in academia

In this section we will have a look at what has been done in the academic fields. Different systems and approaches, and techniques for positioning and locating devices and users are presented.

3.5.1 Overviews

Harle and Faragher (2014) analyzed the state of BLE for IPS in 2014, trying to answer questions like if: *"...BLE can have a significant impact on solving the larger "indoor GPS" problem."*. Their paper is of interest as it did performance testing of the beacons. They placed beacons around a corridor in which they had a person walk back and forth in the corridor with two phones (an iPhone and a Samsung Galaxy S4), and they had him walk slowly. There were also WiFi access points around the corridors that were not placed there by the authors, data about those access points were collected as well. They dealt with the multipath problem by having the gathered data about signal strengths in batches and then calculating the mean value. It should also be mentioned that they generated a fingerprint database with the collected data as a foundation, they mention that this could be done in different ways, for instance with SLAM or by taking manual readings around the venue. When they compared and evaluated they had fingerprint databases for both WiFi and BLE, they found that WiFi had an accuracy of less than 8.5 meter 95% of the time, and BLE had less than 2.6 meter 95% of the time. It should although be mentioned that the amount of BLE beacons were much denser, but they argue that would likely be the expected scenario in an IPS rollout with BLE beacons.

Vlugt (2013) wrote a white paper on beacons back in 2013, explaining the basic concepts and providing some examples of what we can use the technology for. He stated that Nokia was working on some kind of beacon that advertise latitude, longitude and elevation. And that Nokia's technology would make it easy to integrate onto existing map services, as the map services already use that information, the problem is just getting that specific information indoors. Similarly, one could map the beacons advertised information to a database containing coordinates for the beacons' whereabouts.

Yoshida and Manandhar (2017) presents in their white paper on IMES a chip that advertises information that the phone can detect by using the same sensor that listens for signals from the GNSS. Like an extension of GPS (as it also provides floor level information), that can be used with most phones that already have navigation capabilities. This is different from what one gets with GeoBeacon, which broadcasts the coordinate within the BLE packet (which then requires translation into coordinates), with this IMES technology one doesn't have to do that translation. When looking at maps on your phone, the phone forwards the signals it reads from the GNSS to the map. The same process would just continue to do so even when out of range of the actual satellites, the idea is that it would work with the map services without any additional steps, which seems like an intriguing solution. They also describe some devices powered by ethernet that also has WiFi and Bluetooth capabilities. Almost as a beacon network of mini-pseudolites (pseudo-satellite). IMES had a positioning error of less than 10 meters, according to some testing the authors performed. Which seem insufficiently accurate for the artifact's intended use in stores, but the concept is noteworthy when one thinks of the upsides to the other aspects of the technology.

Deak et al. (2012) presents an overview of the state and existence of different relevant technologies back in 2012, looking at complexity, price, precision and evaluating them. They seemed to think that UWB might be the way to go, as they note that it is able to minimize the multipath effect, which is one of the problems with indoor positioning. Additionally, they stated that hybrid systems like the WiFi, GPS and cell-tower based system Skyhook are needed.

Zhou (2017) presents an overview of the mainstream approaches to achieve an IPS, technologies he mentions are IR, ultrasonic, Bluetooth, RFID, UWB, camera vision and WiFi. These are undoubtedly the most mainstream, but there are also interesting alternatives like the IMES variant from Yoshida and Manandhar (2017) and other LiFi/VLC approaches. In the paper Zhou (2017) concludes with having most belief in the WiFi approach, with a fingerprinting database. The overview is rather short but does grant a quick overview over the most mainstream approaches.

Torstensson (2016) wrote his bachelor thesis on an IPS with BLE beacons and provides a state of the art on the positioning. He provides a nice overview over the BLE beacon domain, problems that exists with the technology, different approaches and even some of the vendors that provide the technology. He also did performance testing with varying setups and technologies and had different visualizations of what was the calculated and actual position of the devices in the different tests.

Zaragozí et al. (2015) goes through some of the issues of out- and indoor positioning, like the fact that GPS isn't useful inside buildings and in dense urban areas. Due to signal loss, these navigation systems often switch to inertial navigation using the phone's sensors. The inertial navigation tends to become less accurate the longer it is used, which is one of the reasons why many alternative technologies to help with positioning is investigated for situations when the GPS signal isn't available. As they also point out in the paper that locating the user is only half the problem, the second half revolves around having high quality indoor maps.

3.5.2 Evaluation, analyzing and testing

Ji et al. (2015) analyzed the accuracy of positioning with BLE beacons, corresponding to the amount of beacons. They did this by gathering data on signal strengths, on two different kinds of BLE beacons and for WiFi access points. After a certain amount of data was collected, they simulated what the benefits of adding multiple beacons would be and presented it visually. Their research showed that adding more beacons helps with accuracy, but at a certain point adding more beacons might not be worthwhile. In a room that is 100x100 meters, the accuracy of adding 20 beacons, from 30 to 50 beacons increased the accuracy by approximately 3 meters. Adding 50 beacons, from 50 to 100 beacons also increased the accuracy about 3 meters. Adding 20 beacons, from 10 to 30 beacons, gave a simulated accuracy improvement of 12.5 meters. They also found that the signal from the beacons are weaker than from a WiFi access point, which isn't a surprise.

Mackey and Spachos (2017) has a short paper that evaluates beacons for indoor localization in smart buildings, they do some simple testing on beacons from three different providers; Estimote, Kontakt.io and Glimworm. They also applied filtering with a Kalman filter to improve accuracy (filter that takes measurements over time and outputs estimates that should be more accurate than a single measurement), they conclude that their results show that filtering is necessary and that the kind of filter most suited to use might be relative to the venue. BLE beacons as standalone solution for IPS tend to redeem itself as not optimal, this is what generally Mackey and Spachos say people tend to do to solve the problem: *"This often includes the addition of more beacons for added points of reference and software defined filters to eliminate noise."*. Alternatively, sensor fusion and hybrid method approaches. They used the AltBeacon library for their Android app, which is also used in this thesis.

Zhuang et al. (2016) evaluate an approach to an IPS with BLE beacons, which utilized many approaches to increase the accuracy. Like channel-separate fingerprinting, outlier-detection, extended Kalman filtering and channel-separate polynomial regression for the localization of the smartphone. According to their findings it is better to create fingerprints of each channel that BLE uses to advertise its messages. Their algorithm achieved an accuracy of less than 2.56 meters 90% of the time, with 9 meter distance between the beacons. They state that their algorithm is especially useful in improving the localization accuracy in environments with sparse deployment of beacons, which could be the case in a large retail store. During their experiments they had two "deployments", one with 20 beacons with an average of 9 meter distance between them, and one with 8 beacons with an average of 18 meter distance between. They installed the beacons at around 1.5 meter from the floor, which is better than at the floor, even higher might have been beneficial. They used a stopwatch to record time and assumed that the testers walked in a constant speed (which they were instructed to), to create additional datapoints. They conclude amongst other things that their suggested approach showed more improvement than simply adding more beacons, which tells us that filtering and better ways of utilizing the data and signals are important.

Chiang et al. (2015) has a paper where they analyze the performance of a Pedestrian Dead Reckoning algorithm in an indoor environment. The paper is about them using what they call "Map-Aided Fuzzy Decision Tree" as a tool to improve the technology and simplify the computations time-consuming processing in indoor navigation algorithms. It is an IPS using data from the inertial sensors of the phone and BLE beacons to initialize the process and find the initial location of the user. They make a point of how one problem with using the inertial sensors are that people are different, it is hard to predict our movement and our movement patters differ a lot. They state tuning and calibration can improve the accuracy but is not very convenient in a real-time system. They conclude and argue that their system improves the accuracy and is less computationally heavy because they use decision trees that makes the system follow rules which provide better data.

An idea about the differentiating movement patterns of people might be to learn the user's walking pattern over time, and once the accuracy is good enough, use it to aid the IPS in a sensor fusion fashion.

Haagmans et al. (2017) shows an approach to determine where to place beacons in a 3D space. Important work, as it makes it easier to get better accuracy at venues where IPSs are being installed. They use a starter kit from BlooLoc, which consists of a base station, 15 beacons and 3 tags. The system creates a model which not only shows the solution that provides the best accuracy but shows solutions with for instance less beacons which still provides the specified accuracy. As different scenarios might require different accuracies, and the customers usually concerns themselves with the price.

3.5.3 Micro-location and micro-positioning

These are the papers who had the definitions in subsection 3.3.4 that were argued as describing micro-positioning. What they regard as micro-location, I regard as micro-positioning.

Zafari and Papapanagiotou (2015) looks at achieving their idea of micro-location with BLE beacons using particle filtering. According to their experiments they achieved an accuracy of as low as 0.27 meters in small spaces (1 x 1 meter), and 0.97 meter in larger spaces (11 x 6 meter). Which is alright by only using BLE beacons and filtering. For the scenario of product finding in retail stores, which is large spaces, 0.97 meter might be less accurate than what one would want. They recommend that beacons are placed high in the environment in order to reduce obstacles and signal disturbances, and that one should plan out where to position the beacons before deployment.

In the paper named "Micro-location for Internet of Things equipped Smart Buildings Zafari et al. (2016) looks at the state of the art and various challenges that we face today, and they present multiple concepts and possibilities with the technology. Most relevant of the possibilities for the artifact is the targeted e-marketing with geofencing, which isn't a new idea, but it is very likely to be utilized in system like the artifact. Further on the targeted e-marketing they mention for instance giving customers special discounts, availability of a product he is interested in and providing information of products that goes well with or might be necessary to have with a product he wants to buy. They make a point out of privacy with IPS, and how users might not be too comfortable letting a company know their whereabouts at all times. Additionally, they point out that in order for these kinds of systems to reach their maximum potential, there more people using it, the better it becomes. Therefore, they suggest that winning the user's trust by assuring him the data won't be used for anything other than to benefit him, and they urge that strict laws and regulation to avoid rule-breakers must be created.

3.5.4 Retail related systems

Peiris et al. (2016) wrote a paper where they presented their system SHOP&NAV, which was a system which assisted and helped the users navigate indoors inside a mall. Although while very relevant, it addresses malls and larger venues, which are beyond the scope of retail stores in this thesis. They utilize Bluetooth beacons to help them position and assist the users, they also incorporate some advertisement features into their app. As they explain, the way the navigation works with beacons are that the beacon broadcasts their identifiers. The phone receives the identifiers and forwards them to the database, which then knows what identifiers represent what location. They argue that time is very valuable and will be even more so in the future. Thus, these kinds of digital assistance systems will be beneficial.

Fernando et al. (2016) describes a system in which they use BLE beacons and stickers in a clothing shop to help customers find clothes. The idea is relevant to the artifact in regard to finding paths to products in a store, it does propagate the idea of having beacons as a main source of positioning estimation, and then using stickers for close and high-accuracy dependent positioning. The idea seems to not have optimal impact on aspects like price, setup time, complexity and maintenance.

One of the benefits to be gained by stores digitalizing themselves, by utilizing new technology and using concepts like in the artifact, is data. Hwang and Jang (2017) presents a paper where they show a method to analyze shoppers' movements in a fashion store, they do this with a WiFi based IPS and they propose and use process mining for analysis. It demonstrates some of the data we can generate with IPS and how we can get them. Rather than deeply analyzing the data, they show an approach of how one could do so. They state this is a field in which strong interest has been shown from marketing and retail behavior studies, and it is without doubt that these kinds of data can help the retail industry improve.

3.5.5 Single technology approaches

The approaches described in the papers in this section rely on one technology, it being radio frequency, light waves, sound waves or inertial smartphone sensory data.

Fernández et al. (2007) considered using Bluetooth beacons before the BLE protocol was released, still they demonstrated the concept of using sensor networks and beacons to be able to pinpoint the position of a user or device in an environment. They suggested that the beacons could communicate with each other and work in a mesh network, as that would help the overall accuracy quite drastically. The reason they argue for this is that the beacons are at fixed and known locations, therefore any changes to the signal between beacons might reflect some changes in the environment. When that sort of data is available in real-time, it can be used to take into considerations fluctuations due to changes in the environment, and therefore improve the estimated position of the user. They conclude that this technique reduces the error rate of the position estimation with around 50%, and that an increasing amount of beacons will make for even better accuracy.

Korona et al. (2015) did a summer project where they created an IPS using BLE beacons, their paper is a nice and easy to understand introduction for those looking into beacons as a method of positioning a device. They used what they describe as aggressive filtering to get more accurate positioning, but they debunked it as being feasible because it was simply too slow for real-time use. Although that may be the case, some degree of filtering surely seems to be beneficial in these kinds of systems.

Ionescu et al. (2014) works with the sticker-type beacons, which are more centered towards specific items and objects. The system can help locating and keeping track of specific items, like a keychain. They show that their approach can achieve accuracy of about 1 meter for short distance and below 3 meters for longer distances. They do this by removing outliers in the signal strength, filter using a Kalman filter and at the end they discretize the measured distance.

Lin et al. (2015) developed a system for tracking people in a hospital, they achieved an accuracy of around 5 meters. The premise was that there are many overcrowded hospitals around the world, and as patients are waiting for help they might wander off or move within the hospital. They developed a system to help the staff locate these persons, and they did so with BLE beacons. This is very relevant to a part of the artifact, namely the part that addresses the issue of customers needing help from actual staff when none is available. Instead of customers waiting at a certain location, with or without a queue ticket, they can roam the premises freely and they will be approached by a member of the staff whenever one is available and it is the customers turn. In the case of stores there will be a queue of what customer is to be assisted first, likely the prioritization will be first in, first out. In a hospital the queue prioritization might change due to conditions and severity of disease amongst patients. In a store there are many benefits to a solution like this, it would although require more accurate positioning than what was acquired in this system.

Lazik and Rowe (2012) presents an original approach, localization based on ultrasonic chirps. The paper states that humans can hear frequencies up to 20kHz, while smartphones can detect frequencies as high as 24 kHz, which then leaves 4 kHz bandwidth that can used for data transmission. With their Time-Difference-of-Arrival approach they managed to localize 95% of their test points with an accuracy of <10 cm. Their further work included using filtering and utilizing other technologies to achieve greater accuracy and stability, for instance BLE beacons. As with many of the other methods and approaches this also has some potential problems, it is not completely clear what the total cost and maintenance would be for such a system. Since it requires speakers to play sounds, it might be reasonable to expect it to require a constant power supply. The system needs tuning and configuration at initial setup, but so does many other approaches as well. The speakers/horn tweeters they used cost roughly 2.5$ each, but additionally comes the material and work that must be done in order to add wiring to the speakers. None the less an interesting approach that can be interesting for instance in sensor fusion / hybrid positioning approaches.

Lazik et al. (2014) presents a system in the segment of VLC, that instead of specific positioning is more targeted towards what they call semantic locations. It aims at finding points of interest rather than getting absolute positioning, location rather than position. As they describe it the approach suggested in the paper is more similar to having an invisible QR code, none the less it is relevant and brings some fresh ideas to the table. It explains and presents the problems elegantly and brings up problems like the camera sensors in the smartphones and the fact that we also want the flickering of the light to not be perceivable by humans. They also suggest that future work for systems like this, could be improved by implementing tracking and estimation algorithms to build maps to use for more accurate estimations. In other terms gathering data and building a fingerprint database, which we have seen in many approaches before.

Chizari et al. (2017) published a paper on VLC for IPSs, with focus on dimmable illumination. Although in stores the lighting would normally be set to a predefined level, in environments like offices one might want to be able to change the intensity of the light. It is none the less a positive feature, that makes LiFi even more viable as an option in hybrid systems for indoor positioning.

3.5.6 Sensor fusion/hybrid approaches

In this subsection, approaches for IPS by using hybrid and sensor fusion approaches are covered. They use more than one technology and data source to assist with the positioning.

In their WiFi and BLE hybrid system Pei et al. (2017) found that WiFi positioning suffer from interference, relative to how close a Bluetooth device is. Bluetooth devices does not suffer as much, due to frequency-hopping technology. Which is also supported by Steve Hegenderfer at the Bluetooth SIG: *"Interoperability with other location and wireless technologies like WiFi is actually something that Bluetooth does extremely well."* and: *"Bluetooth is the perfect solution for a noisy area like retail, because of Bluetooth frequency hopping."* (Sterling and Hegenderfer, 2014). The frequency hopping technology allows the Bluetooth devices to switch lanes if some of the lanes on the "highway" presents itself as more optimal, this is meant to lessen the interference amongst signals on the band. The highway being the 2.4 GHz band, and the lanes being different channels in the band. Additionally, they show some different approaches to fingerprinting databases, like the occurrence-based fingerprinting database (which is what one usually sees) and a Weibull-based fingerprinting database. They conclude that their Weibull-based approach has a better performance, but it does not solve the problem with interferences in the signals. They also recommend that one do normalization of the signals for different devices, as the internal components of smartphones vary and therefore different results are produced.

Kanaris et al. (2017) published a paper where they created a hybrid based IPS, by fusing BLE and WiFi data. Additionally, they proposed a new approach to finding the position by using an approach which filters the initial fingerprints after looking at the RSS fingerprints with respect to the BLE devices. They state this approach gives them an optimized small subset of the possible positions the user might be at, which gives them more accurate positioning rapidly. In a RTLS it is crucial that the parts move quickly, there is a relation between speed and accuracy that is crucial in such systems. In their testing they achieved an improvement in positioning-accuracy from 4.05 meters to 2.33 meters, and their algorithm successfully narrowed down where in the fingerprinting database to look and in so improved the computational performance.

Liu et al. (2014) presents a system for indoor localization using the inertial sensors, which goes in the hybrid-approach category, as it uses WiFi signals as well. The WiFi signals are used for initial whereabout discovery, and room-level localization. The authors argue that the fingerprinting techniques are too much of a hassle, in that it is expensive and labor-intensive. They suggest a crowdsourcing technique to make the fingerprinting hassle free, the technique is used for creating and maintaining/updating the database. They call the technique back-tracking, and it includes analyzing the data after a session is done. They achieved an approximate accuracy of around 0.6 meters, with inertial data, WiFi data, fingerprinting and filtering. Around 1.3 meters were achieved in larger areas with less than optimal WiFi coverage.

Delfa and Catania (2014) starts of their paper basically saying that we are always somewhere, wherever we are there is a geographical coordinate identifying the place. These coordinates can be used to connect the physical and digital world and holds the potential to make our lives easier. They look into and show a system that is able to provide indoor navigation with the use of a smartphone, BLE beacons and visual tags on the floor. The system works by having the BLE beacons cover the general whereabouts of the user, and then they stick these small tags (QR code is an example) to the floor. Since the user would normally hold the phone in front of him when navigating, the phone can then scan these codes/tags which enables accurate and specific positioning. A positioning system with "checkpoints" that calibrate the position, and they provide a proof that the concept is viable. It is although subject to problems like the stickers getting worn out, covered by dirt, and camera lenses that aren't clean and can't scan the codes.

Li et al. (2017) has a paper on the topic of indoor positioning with sensor fusion based on VLC and inertial navigation, with filtering techniques to improve accuracy. This is in the domain of positioning using the LiFi technology we have seen previously, together with a phone's inertial sensors. With the filtering they achieved an average error margin of roughly 15 and 40 cm. The authors add to the line of people that seems sensor fusion and filtering is the way to go for IPSs. There are some pros to this specific solution, like it providing high accuracy, being low cost, it can rely on existing infrastructure and it does not emit any electromagnetic radiation. It is low cost in the sense that the venues already need light-bulbs, and although light-bulbs with LED and LiFi technology likely wouldn't be very cheap it has to be looked in a perspective that considers the lifetime of the bulbs. One of the drawbacks are that light can be blocked and reflected, which might confuse the system that utilizes it. There is no doubt that this technology is exciting and that there are many things we can utilize it for.

Chiu et al. (2016) implemented an IPS with WiFi and BLE beacons, fingerprinting and filtering. They divided the WiFi and beacons into sections, and generated fingerprints based on WiFi access points. With this hybrid approach the app can look for the WiFi access point first, and then at the beacons in order to determine a position.

Building onto the future work section of Lazik and Rowe (2012), is a paper from 2015 that presents a system that is able to localize and map out rooms using BLE, ultrasound and the phone's inertial sensors (Lazik et al., 2015). Much like Estimote offer BLE beacons with UWB and mesh networking capabilities, with which Estimote's app is able to map out the room and position the phone in the environment. Lazik et al. (2015) was able to track a user's location with an accuracy of <1 meter. They created their own beacons with BLE capabilities that run on a battery, which are able to make the necessary sounds. Although it is much greater in size than the typical beacon provided from for instance Estimote. This proves that the presented potential problems from earlier, like having to provide a constant power supply from electrical wiring have less foothold. Although it is stated that the ultrasonic transmission requires more power than pure BLE solutions, in this scenario having a battery pack forces the size of the beacon and battery to increase and the maintenance and battery-replacement is much more frequent. With that said it is possible to do this with batteries, and hopefully battery-technology will have some significant evolvements in the near future.

Zhu et al. (2012) wrote a paper on crowdsourcing fingerprinting data for WiFi localization systems, additionally they gathered Bluetooth beacon data to improve the accuracy. This was back in 2012, so it was right after BLE was announced. The paper addresses the issue of not getting user input, which results in low to no accuracy in the system. The system here relies on the input from users, in which they must prompt users for contribution, which causes problems like having an incentive for the user to do so and the fact that the user contribution might be of bad quality. In the artifact this is not thought of as an issue, as the idea is that mapping improvements would be done through crowdsourcing without user interaction other than movement (given that they consent). The incentive for them to allow that data transaction to happen is that it is hassle-free for them, the data can be anonymized (no need for personal data to improve mapping) and the fact that in doing so they gain benefits like better accuracy of indoor navigation and maybe something in the line of special discounts.

Zhao et al. (2018) has a conference paper where they analyze the optimal placement of beacons in a hybrid system with BLE beacons and inertial sensors from the phone, in an indoor localization context. They lay ground for some simple rules on where to position the beacons, that is considered for the performance testing of the beacons in chapter 6's section 6.2. They briefly explain concepts like fingerprinting and triangulation and explains that there is a ratio to how close one needs to place the beacons. Too close and it isn't cost efficient, too far and the accuracy drops, additionally this is dependent on and affected by local variables at the venues. They propose some rules for placing the beacons, like that one should avoid obstacles, they suggest placing beacons around corners and bearing columns and they propose a distance between beacons of 4-6 meters.

3.5.7 Relevant master's theses

Bekkelien et al. (2012) wrote her master thesis on Bluetooth Indoor Positioning, she utilized some hands-free units from Nokia as beacons and placed them around the campus of University of Geneva's Institute of Service Science. Together with fingerprinting the system provided a 50% probability of having a precision of around 1.5 meter. She concluded with the system not being suitable for tracking moving users. However, the thesis was written in 2012 and fortunately there has been evolvements in the technology since then.

In his master's thesis at the Department of Informatics at the University of Oslo, Skjetne (2016) wrote about the utilization of BLE beacons as a tool for paying for tickets at the metro. Although not directly relevant to the concept of the artifact in this thesis, there are similarities in that he also developed an Android prototype app, parts of the beacon interaction will resemble each other. His sub-chapters on context-aware computing, beacons, privacy and the chapter about the prototype is the most interesting and relevant in regard to this thesis. His thesis is more revolved around HCI, user testing and discovering what people think of the system. This thesis focus on presenting and demonstrating some concepts the technology can be used for in the retail store domain. It seeks to answer whether or not the BLE beacons specifically is suitable for the given task, and if the concepts are useful and would be used by stores' customers.

Hearndon (2016) wrote his master's thesis on BLE in intermittently powered devices, which means devices that have a varying access to power. A solar-powered calculator is an example of such a device. This is an interesting aspect and makes for many different use cases. Think in terms of places where one would have low maintenance, as in not having to replace batteries for instance, and one does not have access to or it is not suitable with an electrical infrastructure of sorts. An example used in thesis is farms and bridges, having sensors detecting various aspects of nature and reporting them when it has access to power. Providing lots of useful information and data about the fields and farming, with low maintenance, the trade-off is of course the stability in the stream of data. It would likely not be very appropriate in a setting where real-time stable datastreams are important. IoT actuators could be the recipients of some of these data, for instance in the bridge scenario it could be used for instance to schedule inspection of a bridge if movement over a certain value is detected. The concept of having devices with alternate power sources is in many regards interesting, as it could potentially decrease and in some cases even close to remove maintenance of many small devices. Examples of things it might be helpful for are beacons, digital shelf labels, IoT sensors, etc.

I drew inspiration from the master's theses of Godoy (2017) and Saetre (2017), my earlier fellow students who delivered their work in December 2017, these guys are in this thesis many times referred to as my predecessors. They collaborated on their chapter where they performance tested the beacons, and it is especially that chapter I use within this thesis. The idea was to build onto, and hopefully improve their testing. The performance testing was based on theirs. They also created their own prototype Android apps, one which helped users find their parked cars, and the other helped managers of retail stores make better decision based on data that can be gathered in the store. The app for the retail manager is certainly the most relevant to this thesis, as it revolves around data visualization and collection as a means to help the store improve itself. The data gathering is not explored in-depth in regard to technical solutions, instead the why and what is explored and it is emphasized how much potential there exists in the data.

3.6 Privacy

3.6.1 From an IT-law perspective

Schechner (2016) opens her paper by depicting the struggle of physical stores in the fight with the online giants, specifically she mentions how Walmart in 2015 announced that it was going to significantly increase its investment in e-commerce activity. And she points out how the New York Times looked at it as some kind of admittance to the fact that Walmart struggle to compete with Amazon when it comes to the online customers. She goes on pointing out that one of the tools these physical stores have is *"Omnichannel retail mechanisms"*, which refers to using various online channels in addition to or instead of the traditional ways of communicating with the customers. She goes on by pointing out how beacons allow the retail stores to analyze how the various channels meld together as customers use multiple channels simultaneously, and that half of American adults use their mobile devices while inside stores. Things they look up on their phone are for instance product information, offers and checking the price of competing stores. Shopping is important for the development of local community and neighborhoods, are points that are made when she reflects over why we even want physical retail stores to survive; *"Ensuring that physical retailers remain competitive has large implications for the livelihood of neighborhoods and cities alike."*. She goes on stating that beacons have the potential to "revive" in-store shopping experiences, by having a system that assists and offers the customers things that they want, based on data. Schechner (2016) put it like this: *"From the retailer's vantage point, beacons have* *the potential to provide important and previously inaccessible data that could be used to cut costs and generate more sales.".* Continuing she explains more concretely what BLE beacons can do, and draws an example telling us what kind of things we can learn with IPSs. Like how many people pass by a display, how many people have been at a certain location, where does the flow of people move, what spaces gets too much/too little traffic, how long are people in the store. There are of course a lot more we can learn, and it is when digging into the details of the data and co-relating them with other data things get exciting. From there she focuses in on privacy issues, gaining the user's trust and she goes into specifics about legislations and code of conducts. The reason is important, as she and many before her has clearly stated; there is a huge potential in the technology, and yes there are some obstacles on the way, but without the trust of the users it will never come close to fulfilling that potential. Incentives for the users to allow the trade-off for giving up data for benefits is one aspect. Getting the users to trust the companies and retail stores and having their privacy and rights in focus and in clearly defined terms is of utter importance. She draws points like the fact that people are sceptic when it comes to giving up data even though the data gathering is "frictionless" (it is gathered automatically, without them having to do anything), it comes down to their privacy. The paper which is published in the Albany Law Journal is amongst the ones I have found who most directly and concretely looks at the privacy aspect in the scenario that the artifact "portrays", especially in that she looks at Courts, the Federal Trade Commission and Congress in the legal-domain.

3.6.2 General Data Protection Regulation

Around March 2018 one of the big news around the world were the Cambridge Analytica case, in very short terms it revolved around the company Cambridge Analytica getting access to private information on more than 50 million Facebook users by exploiting some holes in Facebook's user agreements. The whole process around how they got access, and what they used the data for is in a shady gray-zone and people do not seem happy about it. Attorney general of New York Eric T. Schneiderman was quoted by Rosenberg (2018); *"Consumers have a right to know how their information is used — and companies like Facebook have a fundamental responsibility to protect their users' personal information,".* Digital privacy was already a hot topic, and it is important that we put focus on and discuss privacy. Cases like this does not only bring the upside of attention and discussion, it also makes people understandably sceptic against companies wanting to use their data. Additionally, a topic that has been in the wind in and is even more so in May 2018 is the General Date Protection Regulation (hereby GDPR), which addresses what companies do with the data and private information they have on people European Parliament (2016). It revolves around storing the data securely, encrypting the data, access control, having people's privacy in mind, being open and upfront about what you do with the data. For instance, telling the user what data is used, why, by whom, how, where, how long. It promotes transparency and not hiding what you do with the data behind very long agreements that people tend not to read.

The Norwegian Data Protection Authority/Datatilsynet (2017) published a checklist for having "Privacy by design", which consists of six points, with one or more sub-points each. The six main points is as follows:

- Be ahead, prevent rather than repair
- Make privacy a standard setting
- Build privacy into the design
- Create full functionality: Both-and, not either-or (access restrictions)
- Safeguard the information-security from beginning to end
- Show openness

These points are reasonable, and they are generally positive for both the companies, people and society. GDPR seems like a welcomed addition when considering this statement: *"Smartphone owners overwhelmingly use their devices in store to do product and price look-ups, to get all kinds of information to help make buying decisions. They are of course concerned about privacy issues, but they are willing to trade location for benefits. And there is plenty of evidence to this effect, privacy is a sensitive issue but it is something that with transparency and concrete benefits can be negotiated with consumers."* (Sterling and Hegenderfer, 2014).

This section has not contained an exhaustive list of papers and information in academia. These are amongst some of the ones I found most interesting and relevant to the artifact and the domains it addresses, some were mostly inspirational, some contained information that I felt needed to be mentioned, and some had very high relevance to this thesis.

This chapter provide an overview over potential with the technology, and restrictions and obstacles. Many concepts and features that would be a natural part of a system like the artifact have been mentioned, some has not, the general purpose of the artifact will be to portray what a concrete system that incorporates the technology could look like.

4 Development

In this chapter we take a deeper look at how the Android app was made and discuss various aspects and decisions that were made. As well as covering what the backend looks like for the artifact and for the performance testing of the beacons that is performed.

4.1 Phone and beacons

Multiple tools were used in this project, the phone and the beacons being the most important, therefore some specifics about them are briefly presented.

4.1.1 Smartphone - Samsung Galaxy S8+

The Samsung Galaxy S8+ (SM-G955F) used is a typical flagship-phone with new technology and were the first on the market to feature Bluetooth version 5.0. The devices were shipped with Android 7.0, but were upgraded to Android 8.0 in the spring of 2018.

Although the Galaxy S8+ came with a Bluetooth 5 certified chip, it did not support all of the features in the Bluetooth 5 specification (Sims, 2017). Additionally, Android 7.0 did not support Bluetooth 5 either, it was first in Android 8.0 Oreo that support was built into the operating system. And although the beacons used in this thesis came with newer hardware, the supported BLE version was the 4.2 standard (Estimote, 2018a). In the second half of May 2018, Estimote launched some new beacons that came with Bluetooth 5 support.

What this means is that a fully Bluetooth 5 powered setup were not possible to take advantage of during this thesis. The new Bluetooth 5 chip in the phone and the new hardware in the beacons still are advancements and upgrades, and one can therefore assume that it will only affect the accuracy positively.

4.1.2 Estimote Location Beacons

The beacons all ran on firmware version 4.14.1 (non-UWB) and 4.14.3 (UWB) when the performance tests were conducted. The beacons with UWB ran on hardware version I1.2, and the ones without UWB ran on F3.3. The broadcasting intervals and broadcasting power was experimented with, an example of settings in the Estimote Cloud (CMS one can use to configure the beacons and such) can be seen in figure 4.1. Manipulation of the broadcasting power and intervals has direct consequences on the battery, either it prolongs or shortens the span of the battery. Increasing the broadcasting power will

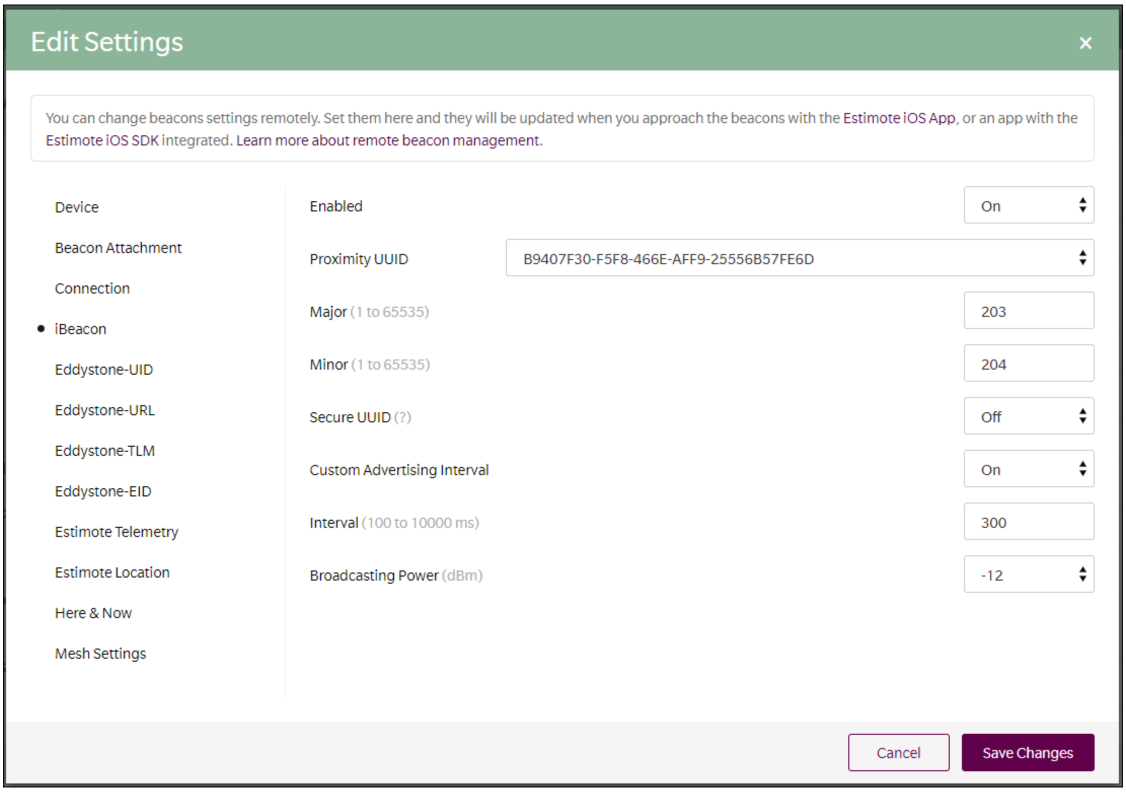


Figure 4.1: Example of iBeacon settings for the yellow location beacon with UWB

result in the signal traveling longer, while increasing the intervals will change how often the signals are broadcasted.

In the Estimote Cloud the user can configure the beacons, configure apps that use the beacons. It also features software for the indoor mapping and locations with the UWB location beacons, and it allows the user to utilize analytics about venues and beacons if set up appropriately. Figure 4.2 depicts the options and gives an overview with details about the beacons used in this project.

Table 4.1 shows what major and minor is broadcasted by the different beacons.

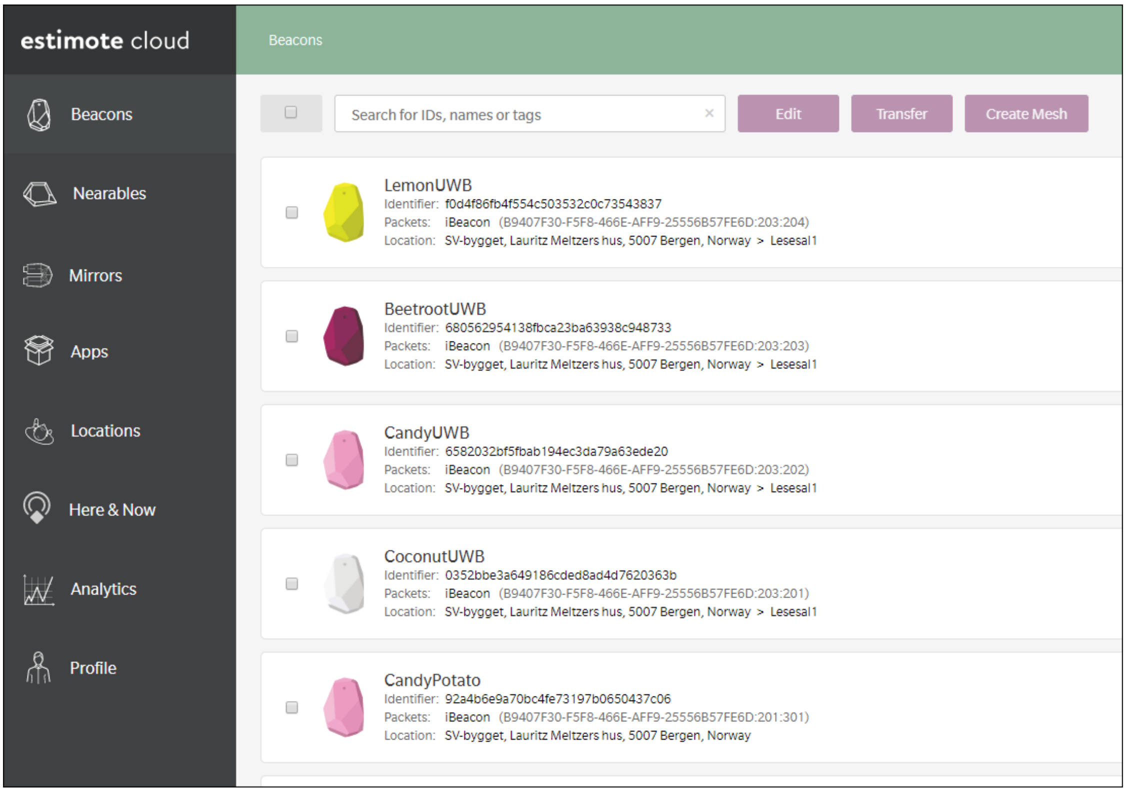


Figure 4.2: The list of location beacons in the Estimote Cloud

The IDs the beacons were set to broadcast			
UUID: B9407F30-F5F8-466E-AFF9-25556B57FE6D			
Major	Minor	Color	UWB?
201	301	Pink	No
201	302	Yellow	No
202	301	Purple	No
203	201	White	Yes
203	202	Pink	Yes
203	203	Purple	Yes
203	204	Yellow	Yes

Table 4.1: Overview over what UUID, major and minor the beacons broadcast

4.2 Database

In the project Google's FireBase was utilized, in this section how will be presented and explained, as well as why it was used.

4.2.1 FireBase

`https://firebase.google.com/` is the link to Google's FireBase, which is a popular database service. It supports various platforms and programming languages, and offers an easily integrated cloud hosted NoSQL database which also is secure. It supports offline storing of the data when no internet connection is available, it also comes with features like the ability to push notifications to the users who have an application using FireBase installed on their phone (Google, 2018b). The two services that were used in this project was the Realtime Database and FireStore.

4.2.2 Realtime Database vs FireStore

The Realtime Database have been used in multiple projects previously, the reason for also using FireStore was because it was recommended by Google for new projects and I was curious about what it brought to the table. Very simply put, FireStore is the new and improved Realtime Database, it features better querying capabilities, data structuring, scalability and overall improvements. In a FireBase blogpost written by Todd Kerpelman he explains that generally they recommend using FireStore for new projects, unless there are some very special needs for using FireBase (Kerpelman, 2017). He also explains that the FireStore is more structured than the Realtime Database which *"basically is one giant JSON tree where anything goes and lawlessness rule the land..."*, and it appears clear that they will be focusing on FireStore for the future. Therefore, it also seemed more likely that an application like Stass, would go with FireStore.

4.2.3 Collections, Documents

FireStore is more structured than the FireBase Realtime Database, it has a document-model database (Kerpelman, 2017). The top layer is called a 'collection' and you can have multiple, in each collection you can have multiple 'documents', which in turn can contain multiple fields of data. A document consists of key-value pairs, and the values can be many things, from integers to objects which contain more data. Kerpelman (2017) put it like this: *"...and these values can contain any number of things, from strings to floats to binary data to JSON-y looking objects the team likes to call maps."*. Think of the collection like a physical folder, in which you can have many sheets of paper/documents, on those documents there can be many types of data.

4.3 Development environments

In this section details about the languages used, the development environments used and some initial requirements that were set for the development of the app.

4.3.1 Programming and data structuring languages

Java and Python were the programming languages used, Java was used for the Android development and Python was used for data visualization and manipulation. They are popular object oriented and high-level languages. Java was used as it is one of the standard Android languages (Google, 2017a), and the Java+XML environment of Android was already familiar. Python was chosen as common areas of use are automation, data-integration and data-analytics (Store Norske Leksikon, 2017). And since I needed a simple environment where I could do the data visualization and manipulate the data with Plotly.

XML is a markup language that can be used for data structuring and is used for the frontend of the Android activities. It is used to define objects and layouts in the screens, like buttons and where they should be placed and so on. It resembles how a web-page can consist of a HTML document, and the HTML elements having some in-line CSS and JavaScript. JSON is a formatting standard, which is used for structuring data. It comes in key and value pairs and can represent and contain the most common elements and values one would find when programming. The data produced from the performance testing is in a JSON format, as that is the format the database is in.

4.3.2 Android Studio and PyCharm

Android Studio is Google's official IDE (Integrated Developer Environment), and it is based on the popular IntelliJ made by JetBrains (Google, 2018c). It is tailored for Android development by the people who maintain Android and is therefore widely used for its intended use. It comes with a visual interface editor to help the user design the different GUIs, and pretty much all the things one would expect from such an IDE. PyCharm, a Python IDE that is also made by JetBrains was very familiar, but the environment was of course tailored to utilize Python's features.

In Android the different screens the user sees is based around a concept called activities, an activity consists of a Java class that implements some Activity-specific methods, and a "layout" which is an XML file describing and containing the various elements in the frontend. Stass has multiple activities, most of them are part of the proof of concept and demonstration artifact. There are also some hidden activities, that are used for the performance testing, step calibration and developer-experimentation.

In the Python development there were no GUI developed, it was used to answer questions like what step sensitivity is most accurate for this project and visualize the data from performance testing in form of different graphs.

Other tools like Trello (basically a virtual Kanban-board) for workflow, and GIT for version control were also used.

4.3.3 Requirements

Before the work with both the Stass app, and the performance testing, some basic requirements needed to be defined. In order to have to some sense of goals along the way, and to have structure and clear progress in the development.

Requirements for the Stass app

There are many things that were imagined as functionality in Stass, but the requirements that I thought the app should be able to have at least to some degree was:

1. Demonstrate the idea and concept to others
2. Work with a database and the beacons
3. Help a user find information about products by various means
4. Know whether it is in a store, and what store
5. Know what products are nearby, and approximately where the user is
6. Keep track over the users shopping-list
7. Able to present a path through the store
8. Save and be able to present analytics and data about the customers in the store
9. Allow the user to disable features like background scanning
10. Able to help the user get assistance
11. Keep a track over the assistance queue
12. Be able to help users navigate the store

Not everything on the list were implemented, a functioning implementation of the queue did not happen. The blue-dot-style navigation was not implemented. The employee-based assistance of the users merely consisted of contact information to the store he is visiting. It came down to time, and the blue-dot navigation and indoor map proved challenging due to reasons like the Google Indoor Map not supporting navigation inside the building on mobile devices. Instead a virtual floor plan were created, just to visualize the concept to the interviewees, it showed products and a path between them based on the selected products in their shopping-list.

Requirements for the performance testing

Since the performance testing is based on Saetre (2017); Godoy (2017), it shares the original requirements, which are points 1-6 in the section 5.2 in their chapter 5. The performance testing in this thesis is an improved continuation. The requirements will stand as is, with the addition of more and better data. The monitoring events are deemed uninteresting and thus is not collected, the reason being that the monitoring events only answers whether a signal from the beacon is detected. Ranging gives us the actual signal, having the signal is all that is needed to determine whether we are within proximity of the beacon. The additional points 7 and 8 is about collecting additional data and improving the data that is already collected, the data collection will be built from scratch.

1. Place the beacons according to predetermined specifications
2. Adjust the settings of the beacons
3. Gather data from the beacons along with our empirical observations of location
4. Store that data in a structured manner for later use
5. Retrieve the data and process it
6. Visualize the data in useful ways
7. Collect additional data
8. Improve the data that is collected

4.4 Software development kits

4.4.1 Estimote-SDKs

This subsection covers Estimote's relevant SDKs.

Android-SDK
Their Android-SDK was the one used by Saetre (2017); Godoy (2017), the most interesting features were monitoring and ranging, which are two different ways of scanning for beacons. Monitoring is often done in the background, so not an active foreground scan, which determine whether or not the user is in proximity of a beacon. This was for instance used in Stass to scan for beacons when the app was closed, and if one were found a notification that told the user that he has entered the store showed up on their phone. Ranging is the active foreground scan, which continuously tries to find signals from the beacons. The SDK also featured connection to the Estimote CMS 'Estimote Cloud' and can be used to help configure the broadcasting power and interval of the beacons.

Proximity-SDK
The first commit on the Proximity-SDK section of Estimote's GitHub was the 20th November 2017, and with this new SDK also came some fundamental changes to the how things worked when working with beacons and proximity. In a post on the Community pages of their website they present how they made changes to how the beacons' default broadcasting packet, the new default being their own Estimote Monitoring rather than iBeacon. Which gave them advantages as Fleet management, Analytics, trigger distance definitions, monitoring for an unlimited number of beacons (Estimote, 2018b). It is still possible to have the beacons broadcast iBeacon packets. The Proximity-SDK is closely integrated with the Estimote Cloud, where one can assign tags to the beacons. So instead of having abstract identifiers such as the UUID, Major and Minor one can simply have the beacons broadcast "attachments" that consist of JSON formatted key and value pairs of strings. Figure 4.3 depicts how one could use these attachments to categorize for instance specific desks in the office. The Proximity-SDK is not utilized in the project, but it was mentioned as this illustrates a different approach to how one can structure the store, sections, products and beacons in the database.

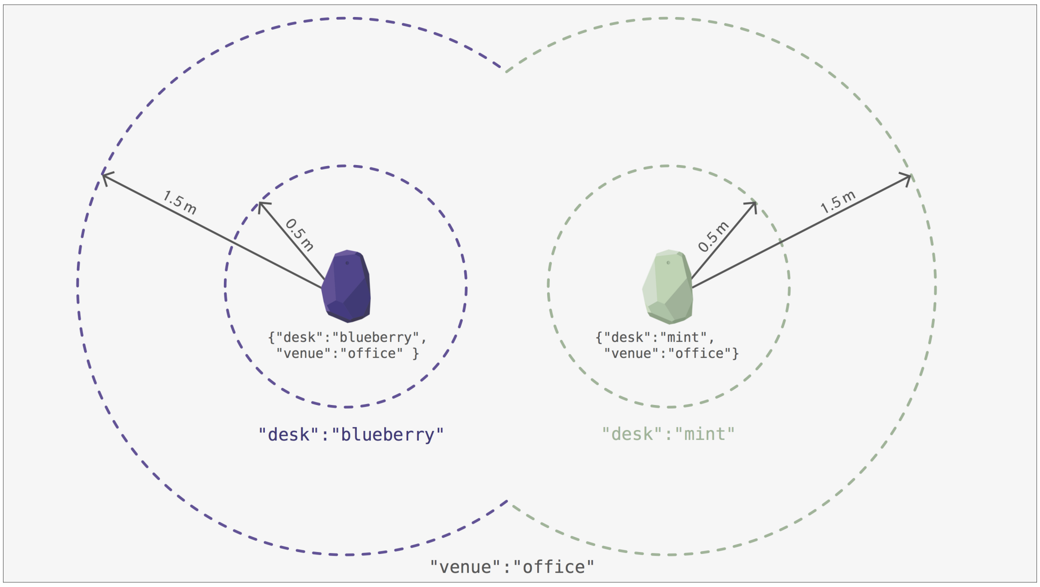


Figure 4.3: An example of attachment-based zones for the beacons and proximity
Source: *Readme for Estimote iOS Proximity SDK, 2017, GitHub.com*

Indoor-SDK
The Indoor-SDK was the one that were interesting when it came to the UWB functionality, although it was limited in terms of what one could do with it. To be able to test and work with the UWB functionality I actually had to acquire an iPhone, as their iOS app had much more functionality. At the end of May 2018, it is still only possible to create a "Location" with the UWB beacons automapping functionality with an iOS device. The UWB automapping is able to create a floor plan automatically, the UWB technology

is supposed to have centimeter accuracy and therefore has good promise for the job. The mapped-out room together with some location data is what Estimote refers to as a ”Location”, which is saved in the Estimote Cloud. One can retrieve these locations from the Estimote Cloud, with the Android Indoor-SDK, but not create them. Once a location is loaded into the app, one can have BLE based blue-dot navigation within the room. A small performance test looking at the accuracy of the automapping of the UWB beacons are conducted, to see if they are as precise as claimed.

Problems with the Estimote Android-SDK
As stated by Saetre (2017); Godoy (2017), they faced some difficulties while using Estimote's SDK. I was also affected by issues, and were during development eagerly paying attention to updates to their SDKs at the *Estimote GitHub page*. For instance they acknowledged the problems, Estimote basically scrapped the SDK and started fresh with new ones. This happened in late November 2017, right in the middle of the artifact development. However, it didn't slow the project down that much, as I was already vigilant to this. I see the reasoning in them separating the proximity and positioning aspects into separate SDKs.

4.4.2 AltBeacon

Since I was already aware that the Estimote Android-SDK might be not completely reliable, during development I decided to also implement the AltBeacon SDK, which offer some of the same features. AltBeacon became the ”main” choice when I realized Estimote were scrapping their Android-SDK, so it is used for the performance testing as well as monitoring and ranging in the Stass app.

4.4.3 Google libraries

Google's simple-pedometer was used to track the steps in the performance testing, it can be found at `https://github.com/google/simple-pedometer`. The only thing that was changed was the step threshold variable, which I did multiple ”step calibration” sessions to determine which was the best to use for the performance testing. Additional libraries from Google include:

- Mobile Vision
- Google Maps, Places, Location and Activity Recognition
- FireBase Code, DataBase, FireStore
- GSON
- Various Android Support libraries

Mobile Vision was used for barcode scanning, Maps, Places and Location were used for instance when attempting to utilize the Google Indoor Map functionality. FireBase was used for database, GSON for JSON related work, and the Android Support libraries were more about the look of the application. Python also used the FireBase libraries to retrieve the data from the performance testing.

4.4.4 Plotly

Plotly is a service used for data visualization, it offers interactive graphs which one can create with various languages and tools. It outputs HTML files, with all the data and functionality for the interactivity that is offered with the graph. It was chosen since a data visualization tool was needed, it supported Python and the interactivity seemed as a nice feature that could be beneficial.

4.5 Data structures and flow - Stass

In this section the overall data structure that is used in the app and the database is presented, and what kinds of data is present and the relations between them. The whole database consists of a proof of concept data structure, so it is not as complete as it would have to be in a real-world scenario. It does although contain a bare minimum needed for actually making the proof of concept functional.

The way the hierarchy is set up in the FireStore a collection consists of multiple retail stores. In this project, there only exist one store in the database. For a store, beacons are assigned in the database. In the database the beacons represent a group of products, as that seemed a more likely scenario than having one beacon per product. However, if using ESLs, then the scenario of one beacon per products becomes more viable.

4.5.1 Store

The store key or ID is in the database set to the UUID that the beacons broadcast, which is common for all the beacons, as can be seen in table 4.1 in the subsection 4.1.2. Additionally, the store object contains standard information about the location and the store, 4.2 shows the values of the store object.

Store	
UUID	B9407F30-F5F8-466E-AFF9-25556B57FE6D
LatLng	60.388437,5.324578
Location	Fosswinckelsgate 6
Email	support@firma.no
LogoUrl	clker.com/cliparts/3/9/e/F/7/H/generic-company-logo-md.png
Name	Generisk Firma AS
PhoneNumber	004712345678
Type	Kiosk
Webpage	www.google.com
Majors	List of majors

Table 4.2: Values in a store object in the database

4.5.2 Sections

Table 4.3 and 4.4 shows the Major and Minor objects in the FireStore, they do contain limited information apart from lists of its children. The reason is that it is a hierarchy to it, also more information and data would likely be added. For instance, for geo-fencing and zone based interaction one would likely want to be able to identify both larger and more general areas as well as specific positions. By comparing the ID of the major and minor with the table 4.1 one finds that the object in the database is what is tied to the pink non-UWB location beacon.

The LocationObject consists of a column and row identifier, so that it can be utilized for the demonstrative path and product-finding, the column and row is specific points in the "map/layout" of the store as seen in chapter 5's figure 5.6. This would although likely be different, if it for instance was a scenario where Google's Indoor Maps were used maybe it would have been specific latitude and longitude bounds/zones for areas and specific coordinates for product placement.

Major	
ID	201
Section	Drikkevarer
LocationBounds	LocationObject(Row, Column)
Minors	List of minors

Table 4.3: The major object and its values in the database

Minor	
ID	301
Grouping	Mineralvann
LocationBounds	LocationObject(Row, Column)
Products	List of products

Table 4.4: The minor object and its values in the database

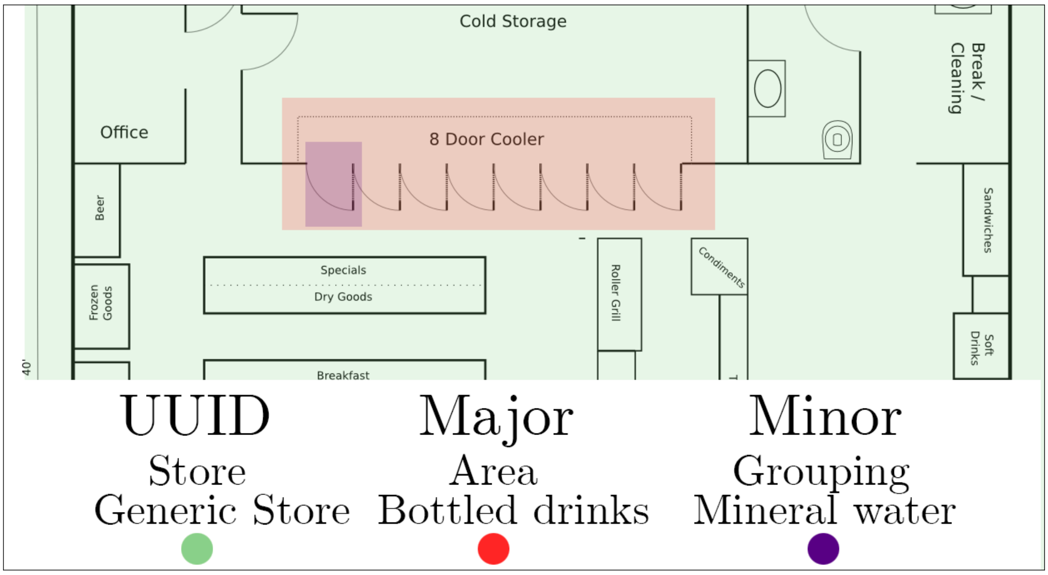


Figure 4.4: Floor plan visual example of how one can divide the store into sections

Figure 4.4 shows a visual example of how one can divide and structure the store in relation to the beacons, which is the structure used in this thesis. Figure 4.5 illustrates the same concept, in a different perspective. In the minor/grouping part one would then have for instance specific types of mineral waters. This approach seems more appropriate for use cases that only use BLE beacons, rather than for instance ESLs with BLE.

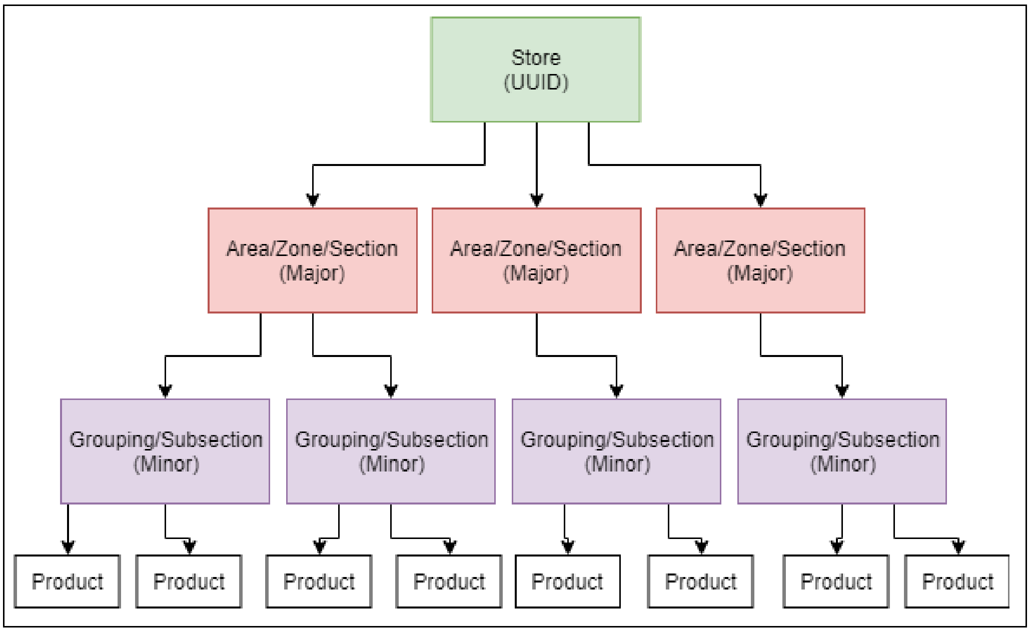


Figure 4.5: Hierarchical example of how one can divide the store into sections

4.5.3 Products

Table 4.5 shows the product object, the Coordinates value is the same as the earlier seen LocationBounds, but one would here expect a much more specific location, whereas the 'Bounds' refers to more areas and section. These objects are incomplete, or one can call it the minimum viable solution. They are supposed to be better, more detailed and larger. For proof of concept it is considered sufficient basis for the Stass Android app.

Product	
ID	7070841001354
Name	Cola 0.5
Coordinates	LocationObject(Row, Column)
Url	nettbutikk.spar.no/varer/drikke/brus/coca-cola-zero-5000112595550

Table 4.5: The Product object

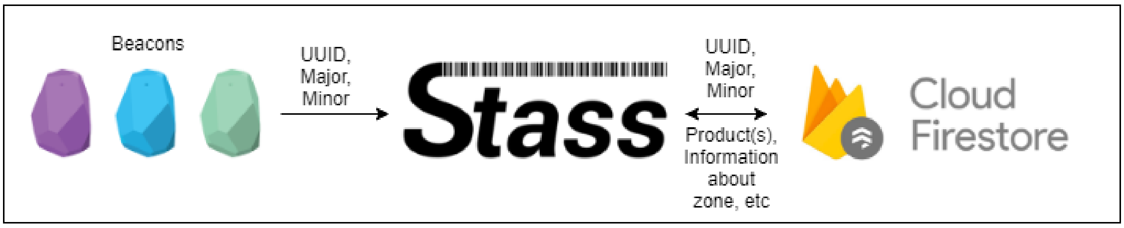


Figure 4.6: Dataflow from beacons, to Stass, to FireStore, and then back to Stass

4.5.4 Dataflow

Figure 4.6 shows the dataflow in Stass, from beacons to FireStore. One of the really nice things about FireStore, is that it features serialization of objects, so rather than having to define the data structure in the database and then fill up every field accordingly, one can simply upload the POJO (Plain Old Java Object). Figure 4.7 shows what it looks like in the FireBase FireStore web interface, when a single store is added. Retrieving the Store object is also simple, we take the UUID we receive from the BLE packets the beacons broadcast and use it to find the Store object in the database.

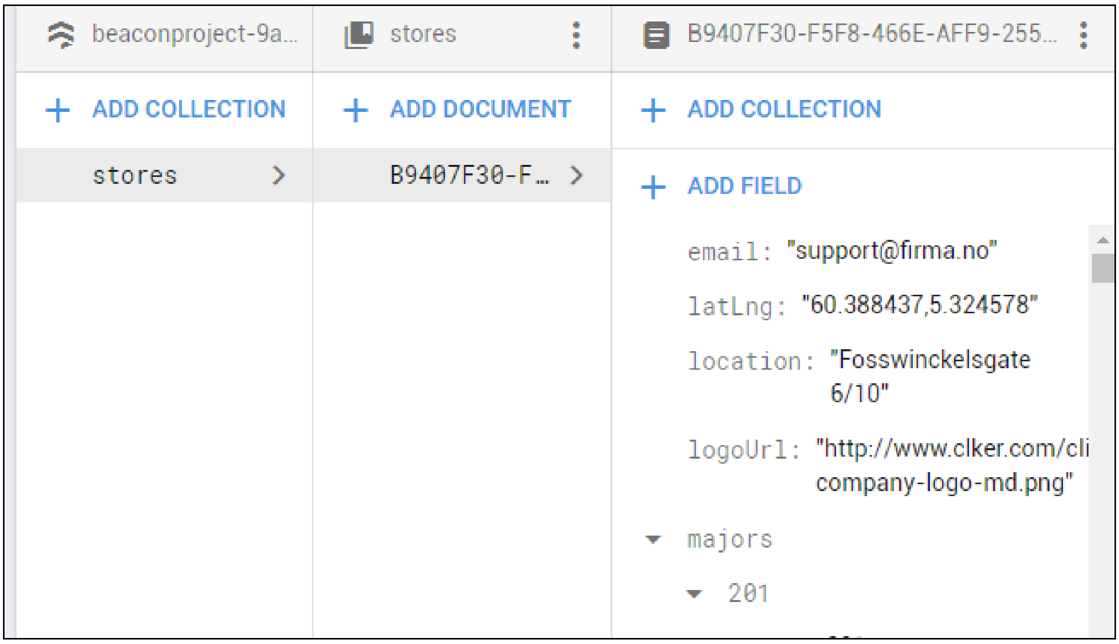


Figure 4.7: A small piece of what it looks like in FireStore, with a single store

Code snippet 4.1 contains a method from the class that handles drawing of the grid, that contains the store layout, path and products. It is a simple proof of concept feature, which means were to illustrate to others the purpose of the shopping-list navigation. The drawPath() method calls another class, and gives it the inputs: the map(grid), what the start and destination points are, what checkpoints it has to go through and what obstacles exists. It uses the returned path to draw the green path onto the grid. The products in the FireStore has information about which points they are located at, so that's why the path changes based on what products are in the shopping-list.

```
public void drawPath() {
        Paint color1 = new Paint();
        color1.setColor(getResources().getColor(R.color.pathcolor));
        PathFindingHandler pathFindingHandler = new PathFindingHandler(new
            NavigationMap(start, destination, checkPoints, obstructions, map));
        pathDrawingPoints = pathFindingHandler.go();
        for (PathTile pathTile : pathDrawingPoints) {
            drawRect(pathTile.getRow(), color1, pathTile.getColumn());
        }
    }
```

Code snippet 4.1: The method that draws path and tiles for the shopping-list navigation

Code snippet 4.2 shows how the nearby products are found. The way this works is that initially when the beacons are detected, we find the section/areas and products associated in the database. When we have that, for the sake of proof of concept, we categorize all of the beacons' associated products as nearby if the beacon is less than five meters away, the number five were an arbitrarily picked number. In this project the regions found were stored in what is known as the SharedPreferences, as it was an easy way to keep track over what regions were within five meter distance. It is likely not the best choice for an app that is to be released on Google Play. However, for this proof of concept app it works sufficiently, and it works by saving Key-Value pairs of data. It saves the whole identifiers (UUID:Major:Minor) as a string, for each beacon that is within five meters. A store object is passed in and contains all the majors, minors and products. In the end it returns a list of all the products that are categorized as nearby (within a given distance).

```
store, listOfProducts, listOfNearbyRegions
for region in listOfNearbyRegions:
    for major in store:
        if region contains major:
            for minor in major:
                if region contains minor:
                    for product in minor:
                        add product to list of products
return listOfProducts
```

Code snippet 4.2: Pseudocode for the retrieval of a list of nearby products

4.6 Data structures and flow - Performance testing

In the Firebase Realtime Database that is tied to the performance testing, there are three kinds of data. Data about the performance testing, data from the step calibration and the statistics from the step calibration. The step calibration is used to generate the step-data, and the step-data is used as input when testing the performance of the beacons.

4.6.1 Step calibration

In the step calibration part of the database, there are multiple step-sessions, each session consists of me walking a given distance, and both me and the app counts my steps. The data that is gathered in a step-session can be seen in figure 4.8, and multiple sessions with different inputs will ultimately be able to pinpoint the most optimal sensitivity setting for the performance testing of the beacons.

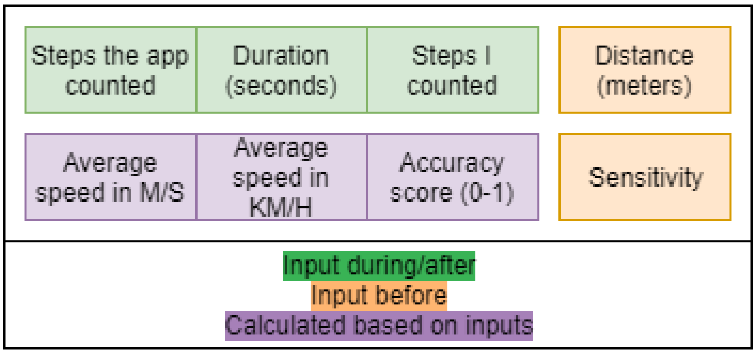


Figure 4.8: The data that is collected in a step-session

The step calibration had to be done as the step detection and counter implementation that was provided by Google came with a predefined sensitivity setting value that specified how sensitive the step detection would be. Various sensors like the accelerometer in the phones are quite sensitive and can pick up very small movements and changes, additionally when the data gathering for the performance testing would be carried out there were one obvious problem. Which was that the phone would be in my hand in front of my abdominal area as I were conducting the tests, so it would not be in my pocket like often is the case. The solution I came up with was to do a calibration of the sensitivity setting, to find the most accurate one to use for the beacon performance testing. The way I decided to find this specific sensitivity was to measure up a distance, and walk that distance, while counting my steps, and let the app do the same. And having samples of different distances and sensitivity settings, to be able to find the optimal one. Figure 4.9 portrays how the flow of "calibrating" the step recognition was conducted, and how the data moved from a to b. At the end of the StepCalibration.py script, it uploaded the previously mentioned 'StepData' to FireBase. The interesting and relevant data that were generated is presented in section 6.1 in chapter 6.

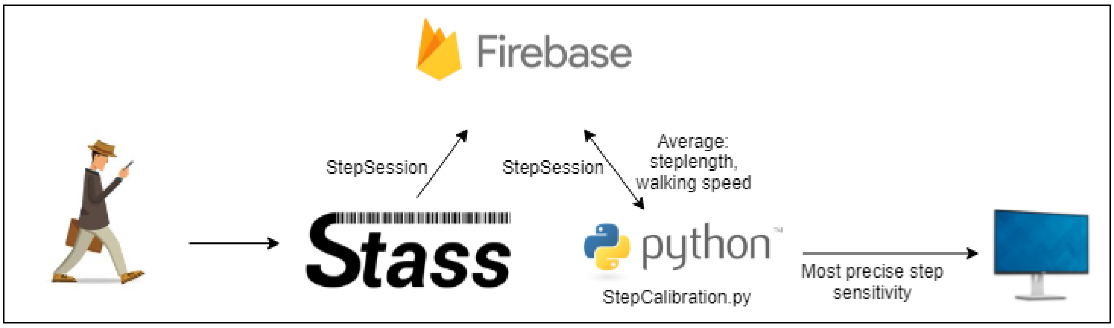


Figure 4.9: StepCalibration through Android, FireBase and Python

4.6.2 StepData

The StepData is a very small part in the database, it has three values; Average speed in KM/H, M/S and average length of my steps. They are updated every time the step calibration script was executed, and the values are used as inputs for the beacon performance testing.

4.6.3 Beacon performance testing

The data in each beacon performance session is also hierarchically structured, the top layer of a session object begins with data about the session, and information about what settings have been used, as well as some summarizing statistics about the session. In the 'Scans' part is where all the scans that utilizes the inertial sensors for step recognition and the received BLE packets are contained. Figure 4.10 present the data-types visually, the only thing that is missing is details about each specific scan. How many scans are tied to the duration of the session, and the scan period and pause between scans settings. If the pause between is 0 milliseconds, and the duration of a scan is 1000 ms, you would have one scan for each second that the session lasted (which is the case in this project).

Figure 4.11 shows what a single scan object looks like, and its various data. A scan will contain information about all the beacons seen, but how many it sees/detects each scan vary from 0-7.

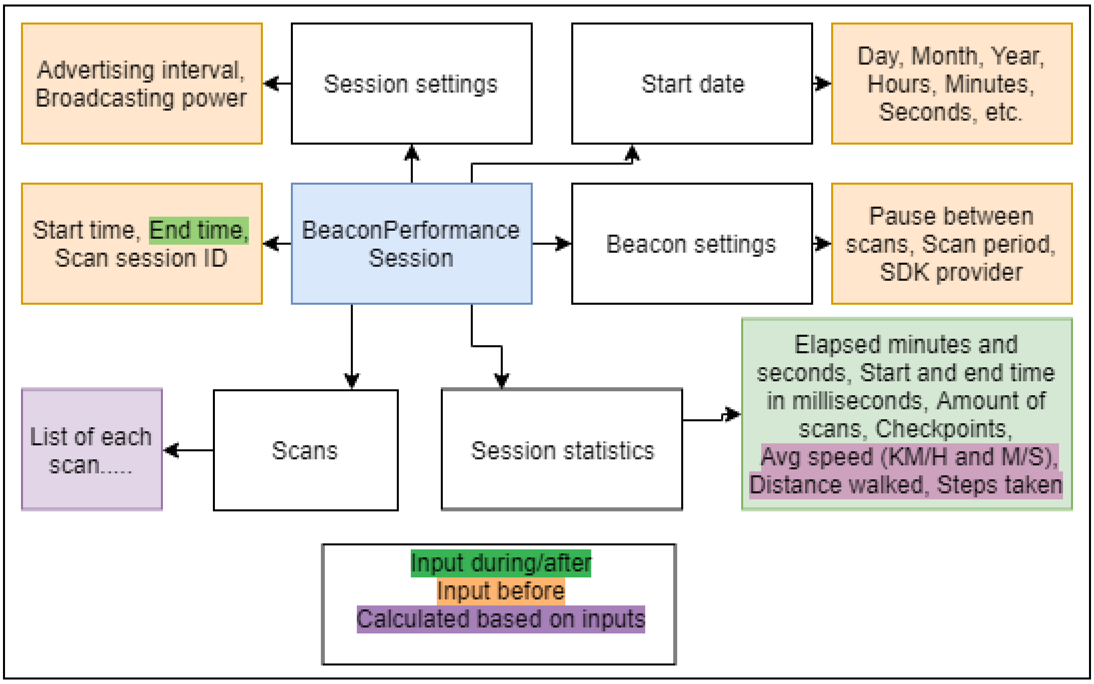


Figure 4.10: The data that is collected in a beacon performance session

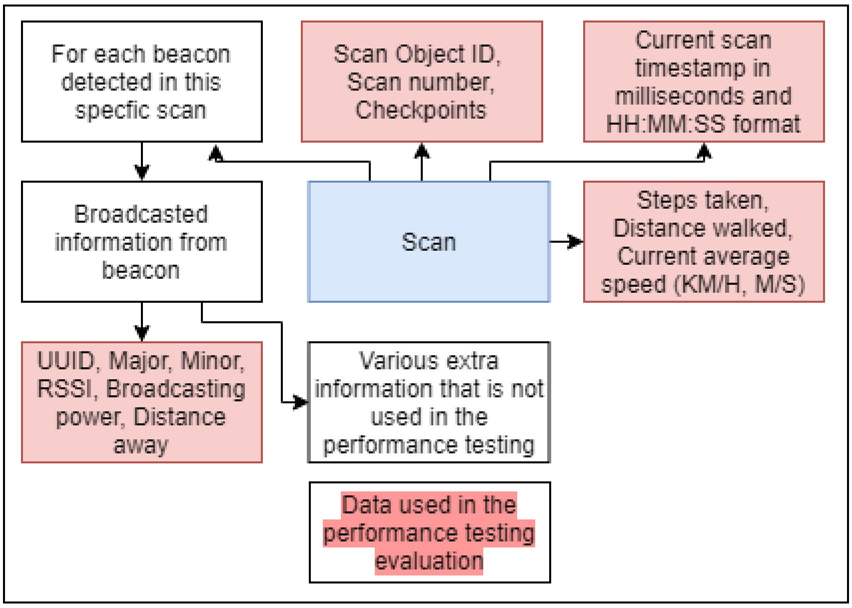


Figure 4.11: The data that is in a single scan object in the database

4.6.4 Dataflow

The performance testing was integrated as a hidden option in the Stass app, as more or less all the tools to do the testing was already in Stass. A new activity was created which featured a GUI, displaying some of the data in real time. This was done so that while testing one could monitor in real time that things were functioning, which avoids wasting time recording data that is incomplete. The flow of data, and the software-services used in the performance testing can be seen in figure 4.12.

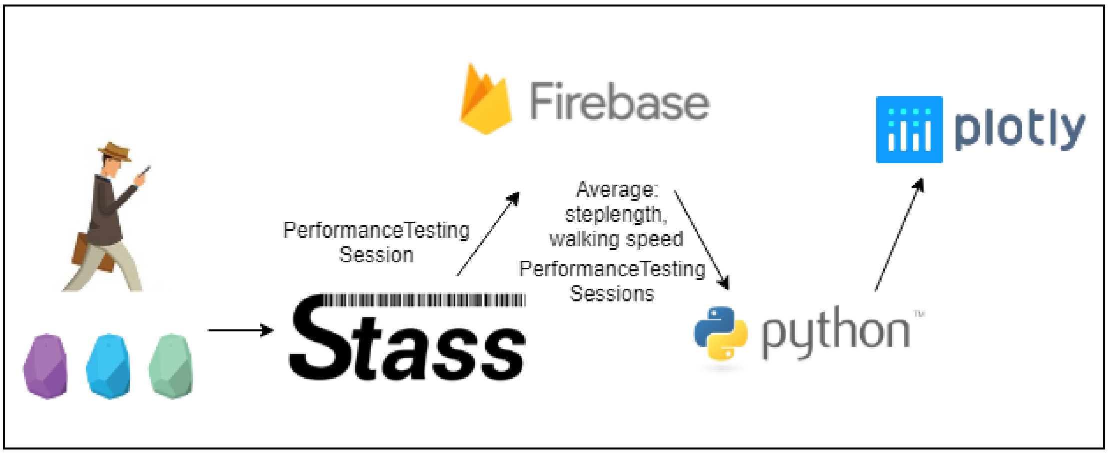


Figure 4.12: Performance testing through Android, FireBase, Python, Plotly

Once a session has concluded, it is uploaded by pushing a confirmation button. It is not done automatically, as one might get hiccups, problems and disturbances while doing the testing due to outside factors. In these cases, it is preferred to not upload the results, rather than having to remove the bad sessions later.

```
phoneY = 0.7, phoneZ = 1.1, beaconY = 0.0, beaconZ = 2.2 //Constant values
phoneX = 0.0, beaconX = 0.0 //Changing values
meters = 5 //Meters between the beacons
for session in database:
    if sessionNumber > 40: meters = 2.5 //First 40 tests were with 5.0 distance
    for scan in session:
        for beaconsSeen in scan:
            for beacon in beaconsSeen:
                beaconsBetween = lastCheckPointNumber - beaconNumber
                beaconX = meters*beaconsBetween
                if checkPointScan: //Phone and checkpoint is aligned on Xaxis
                    phoneX = 0.0
                else: //We have to estimate the phones X position
                    //For instance steps*avgStepLength or seconds*avgMpS
                    phoneX = calculateXPositionBasedOnData()

            distanceBetweenPhoneAndBeacon = pythagoras3d(phoneX, phoneY, phoneZ,
                                                beaconX, beaconY, beaconZ)
```

Code snippet 4.3: Pseudocode of the iterations to find all the distances from phone to beacons

Code snippet 4.3 shows a mix between pseudo and actual code for how I found the distance between the phone and the beacons, which was needed to say something about whether the AltBeacon SDK's distance estimation was correct. The code is more or less what is needed to get distances to every beacon, at every scan. Additionally, there are things to track like what distance setting between the beacons, what settings are used for the beacon broadcasting and so on. Filtrating and using techniques to increase the accuracy and remove outliers are also possible to do here. The lastCheckPointNumber and beaconNumber refers to the checkpoint and beacons position, an integer between 1-7 (7 checkpoints, with an adjacent beacon each).

The graphs and data that is collected and generated is presented in chapter 6.

5 Artifact - Stass

In this section the main artifact of the thesis is covered. The parts that was implemented in the Android app, to demonstrate to the testers and to familiarize myself with the technology are presented, and some of features that were not implemented are also described.

5.1 Stass - Store assistant

Stass (**St**ore **ass**istant) is an Android app, but it is more than the app that has been developed. Stass is a concept and vision of how we can use technology to improve retail for the future, and how to do so. To best explain, we will first go through the concrete concepts that such a system could implement. Then the parts that been implemented in the Stass Android app is presented.

5.2 Concrete concepts

In this part we will look at some of the concrete concepts that can be used to improve the customers experience in retail stores and the retail stores' performance.

Firstly, we will look at assisting the customers, assisting in this context can be divided into two main categories; Employee based assistance, and app-aided assistance (self-help). This concerns the times the customers do not already have the knowledge and isn't able to find the necessary information about products by reading at the box and using the available brochures, video-demonstrations and such. In this scenario the customer might be insecure about whether he wants to buy the product, and assisting the customer can therefore result in customer satisfaction as well as avoidance of lost sales. In this 'Stass'-scenario, the stores will have fewer employees that one sees in traditional 'Brick&Mortar' stores. One of the reasons being that multiple aspects and processes in the store have been optimized and digitalized. There are although without question use for physical sales and customer service staff as well, and when they are fewer it is even more important to place them at the right locations. So that the customers can get assistance from the staff when needed. A common scenario today when a customer wants assistance by the staff the customer has to find the staff, and sometime also wait in line or draw a queue ticket. This wastes the customer's time, which could be spent more sensibly.

5.2.1 CloudQueue

CloudQueue is a concept, in which you have a cloud-based queue in stead of the physical queue machines we have today. One upside of queues in general is that it is structured and let the customers know they will get help, and it is fair as they get help based on when they requested help. One downside is that people will then have to stand around the station and pay attention to the queue number, which has several negative effects: It might get crowded, people might pile up and take up space that others need to walk. If it gets crowded people might become impatient, resulting in grumpy mobs in front of the stations that give a bad impression to the newly arrived customers in terms of how the store is ran and the other customers' satisfaction. CloudQueue takes the upsides of having a queue and removes many of the downsides.

- Low cost and better for the environment
- Smoother queues
- Free-roaming in-store
- Customers don't need to look for staff
- Increased sales and customer satisfaction
- Avoiding large groups of people around the stations
- Potentially additional data generated
- Use the data to adjust staffing

It reduces the cost of the installation of the queue machine system, as well as cost for paper. As well as production of the parts and paper. It allows for customers to leave the queue by stating they no longer need assistance in the app (or auto-remove them if they leave the premises), which reduces hick-ups caused by people getting tired of waiting and leaving. It allows for the customer to wander the store and look at other things, which is a huge advantage. Having them wandering lets them see more of the store might lead to additional sales, they can walk and look around instead of standing in one spot and wait for assistance. One avoids potential large mobs of annoyed people in front of the stations which itself is a big plus, and while they walk around they might generate additional data points that the store can use for other purposes. When it is the customers turn to get assistance from the staff, the staff-member that is available is guided on their work-phone to where the customer is in real-time so they are easy to find.

5.2.2 Self-education

Self-education is about the customer finding information about the products themselves, and this is one of the larger features in such a system.

Finding product information can be solved by:

- Customers scanning barcodes on the products with the app
- Customers selecting the product from a list of nearby products
- Customers searching in the app (product names, product numbers, etc.)
- Customers using the camera to figure out what the product is through image recognition
- NFC based shelf label-tapping with the phone

The question then becomes, where will this information come from? Fortunately, product information is often available online from serious vendors and producers of various products, and as many retail stores also have an online store a lot of information is already available. For this to be really valuable however, it is essential that the products are well documented and that as much information as possible is available. Mounting-descriptions, size specifications, customer reviews, necessary add-on products, related products and so on. One needs to build a product knowledge base, which one can reinforce with data generated in the online store and the physical stores. There are a lot of benefits of having these great product knowledge bases and providing access for the customers:

- Requires less staff to aid the customers
- The staff will also become more knowledgeable when it is easier to find information
- Less wrongful use of the products due to increased knowledge of how to use
- Less warranty cases and waste due to the point above
- Can increase sales, as it becomes clearer what additional products are necessary
- Reassures the customers that the store knows its products and the things it sells
- Improves the overall customer satisfaction

5.2.3 In-store navigation

In-store navigation is another problem completely, which revolves around finding the actual product in the store. If we know where the products are, and we can find the users' location, and we have a map over the store then we can help the customers find the products. The indoor navigation is what enables for instance the shopping-list-based navigation, having a pre-selected list of products to be guided to in the most optimal way when entering the store. This of course requires some backend systems that are neatly and thoughtfully designed. An interesting dilemma is solved with in-store navigation and shopping-list-based navigation. Generally, the stores wants the customer to stay as long as possible, as the longer the customer stays in the store the more likely it is that he'll buy additional products. The dilemma is that at the same time the customer often wants the opposite, they want to spend as little time as necessary in the store, and rather spend their time doing something else. Shopping list and in-store navigation offers a good solution for those in a hurry or being serious about spending as little time as possible, the stores can still have their "maze"-layouts and set the stores up in such a fashion that people use as much time as possible in the store.

- Attracts customers that dislike spending time in stores
- Still allows normal customers the same experience they are used to
- Resemble Click&Collect, but the customer picks the products himself
- Customer still gets "close encounters" with the products before purchasing
- The same concept could also be done for the storages/warehouse

Many of the same concepts could also be done for the storage, many large retail stores have very large storages. For instance, product navigation in artificial reality-goggles or head up displays in their forklifts, showing them the way to where the products are located. The monitoring of products could also be done to keep inventory-accuracy high, and one could for instance do various asset tracking on the pallets of products, forklifts and such to find aspects to optimize in the storage. For instance, one can analyze the time used, and see that a very popular product is placed too deep into the storage so that the storage-employees used an average of extra 15 minutes per day just to travel to the end of the storage. In that scenario finding the product a more suitable location closer to the where the products are handed over to the customers seems like a good idea.

5.2.4 Process optimization

Process optimization isn't directly a feature for the customers but is rather about optimizing the processes and tasks in the store. Improving those processes will although be positively beneficial to both the store, the employees and the customers. What is these processes, and how can we improve them? Going through all of that could be its own thesis, but some examples and places to start will be covered.

- Dynamic and automated pricing
- Inventory and stock
- Reduced theft
- Easy for the customers with automatic payment
- Many things move faster, more fluent and more efficiently, also in the storage

Dynamic and automated pricing keeps the store competitive in the price market, which is essential today. This is very common today with the ESLs, and it also frees up a lot of the staffs time in printing manual prices and keeping track over prices. The point on inventory and stock is about having better accuracy, for instance in the case of Amazon Go where the idea is that they have 100% control over the flow of products. Additionally, we can have dynamic and automated product ordering from the suppliers, with good accuracy and reliability. The shelves in the store that needs to be filled with products could be filled in an optimal fashion, as products sell better if they are at their designated space in the shelve, rather than back in the storage. This also exist to some extent today, but having accurate inventory is crucial for this to work. One could surely adopt machine learning and such techniques to avoid running out of products and ordering way too many products. Holidays, sales, weather, events, there are many variables to consider when ordering from the suppliers, but it should be feasible to get to a place where minimal human interaction is required. Obviously having accurate and precise inventory is a benefit, and if the customer can trust the store to have the products it is surely a selling point. Who doesn't hate going to the store to buy a specific product, and then they are out of stock? Eventually run one could perhaps reduce drastically or even remove the "doing inventory" part where multiple hours are spent manually counting all the products. Having this Amazon Go-like concept also could reduce theft, as the system knows what the person has taken, and automatically bills them when they leave the store. Which is simultaneously easy and convenient for the customers.

Regarding RQ3 which asks what we can do with the data from Stass, it is clearly many processes that can be improved based on statistics and the utilization of the data we can gather in-store. It doesn't need to be total automation of all the tasks, some places might benefit from simply being able to make adjustments based on certain variables. Like how it is important to have enough stock of a product, it is also beneficial to not keep the customers waiting for assistance when they need it. For instance, Google has for many stores these days an overview of at which days, and which times there are most people or "traffic" in the stores. For some it is statistical and based on data over time, and for some venues it also shows in real-time. Such data could for instance be an important variable to utilize when it comes to planning the staffing and could maybe open up for more dynamic working hours in the stores.

5.2.5 Statistics and data-utilization

Godoy (2017) found that there was useful value in gathering data about customer movements inside a retail store, and that there were lots of additional data that would be valuable. There are surely many interesting patterns and trends to be discovered in analyzing the data, but there is also a privacy concern within this domain. There are probably a very large number of things one can use the data for, likely even more so in these days with popular buzzwords being big data and data-mining. Taking the data and meta-data from the retail chain's online store and use them with data from all the physical stores, might provide lots of useful new insight. It could be view in relation to data about weather, time, events, sales, traffic data and what not. For each of the respective stores this combined with local context can give even more answers, and although I do not know everything the data can be used for; it is undoubtedly a lot.

It isn't all about the stores and maximizing profits, it is also about making the life better and easier for all parts concerned, especially the customer. As one would expect the process optimization relies on amongst other things statistics and the utilization of data, the same relation can be found in the next section about advertising and marketing.

5.2.6 Advertising and marketing

Offering the customer a personalized experience within the store can be beneficial, although some will be skeptical as it requires the use of data about them specifically. One solution to the skepticism could be to simply notify the customer that for the functionality to work (or work optimally), the use of data about him needs to be collected and utilized. At the same time, one should offer the action to let the customer opt-out of the functionality, and perhaps select what parts he would like to opt-in on.

An example of what we can do with proximity based and contextualized advertisement in physical stores are for instance letting the user know that the item they picked up and are likely going to buy, cannot be used without another product. Like how one needs a drill to use a bore bit. The customer could be presented with what others who bought the same product also bought, and in these presentations the customer would of course have easy access to additional information on the product. There are many interesting things in this domain, and the more we know and can represent in a machine interpretable fashion, the more we can do with recommendation algorithms and the likes. What can we learn about relationships of the products, what products fit with each other? What will be the best buy for the customer based on experience of other customers and prices? Would it be better for the store to offer the customer a discount on a more expensive product than what they are currently considering, or would it be more economically beneficial to the store to present a cheaper product in which they make more money? If we take into consideration all such factors, then one should with time be able to have powerful recommendation-abilities in the system.

- Advertisement
- Retargeting
- Upsell
- Customer history
- Loyalty (visit number 100, birthday)
- Special occasions and events
- Sales campaigns

Above are some points that one could use in a marketing perspective in such systems as Stass, advertisement do cover many of the other points, but for demonstration some concretes are in place as well. Retargeting is for instance something that could be utilized, most of us have experience retargeting already. When you look at a product in an online store, and that product pops up in ads on your computer and phones for the next few days, you have become a 'victim' of retargeting. This could be very powerful with systems like Stass, as one can do this in a physically and digitally merged fashion. Another aspect one could have is upsell by showing alternatives to the product the customer is considering, with a more data driven approach with cold hard facts about why the system believes the alternative might be better. This would perhaps cause a decrease in the need for human upselling, but not necessarily, human connection, charisma and playing on the customer's emotions are powerful tools not easily built into machines. It is although of course possible to have the app-enabled upselling as a supplement, there doesn't have to be one or the other. Customer history could be used, an example is if the customer usually buys a product around the same time each week and one weeks goes right past it, maybe he would appreciate a notification reminding him? When there are special events in the area around the store, like Olympics, festivals and such, the store could use the information for various purposes. Building loyalty to the customer is important and keeping track of a customer's visits and birthday allows for giving personalized discounts. Sales campaigns can be tailored to fit better with the regular customers and people who live nearby the store, and even the kind of people that tend to visit when walking buy. The point here is merely to illustrate some of the potential when it comes to marketing, but keep in mind that privacy is something one would need to show respect and solve in a good fashion.

5.2.7 Content Management System

As we have seen with the vendors who provide ESLs, it is crucial to have a good backend system to keep track over all the information and data that is used. The standard for the ESLs seem to be having a database linking the products with information, prices, stock, etc. to the ESLs, the way they are paired is by having a smartphone or some sort of scanner which scans the ID of the ESL and the ID/barcode of the product. Then the ESL shows information for that product and is updated automatically from the backend through the wireless access points that are placed around the store.

There are quite a bit of information and data to structure and store, it would likely become large and complex rapidly. Like product information, location of products and ESLs (also in relation to the map-provider), data gathered in-store like customer and shopping cart movements. Sales numbers, stock information, employees, CloudQueue, targeted advertisement, geo-fences, planograms, heatmaps, crowd-sourced fingerprints, there is a whole bunch of information that could be useful to the store and the customers. Likely the system will consist of multiple individual databases, and it is essential that it is well configured and works smoothly. Figure 5.1 shows how one could imagine some of the parts working together, merely to illustrate the point that there are many moving pieces in the puzzle.

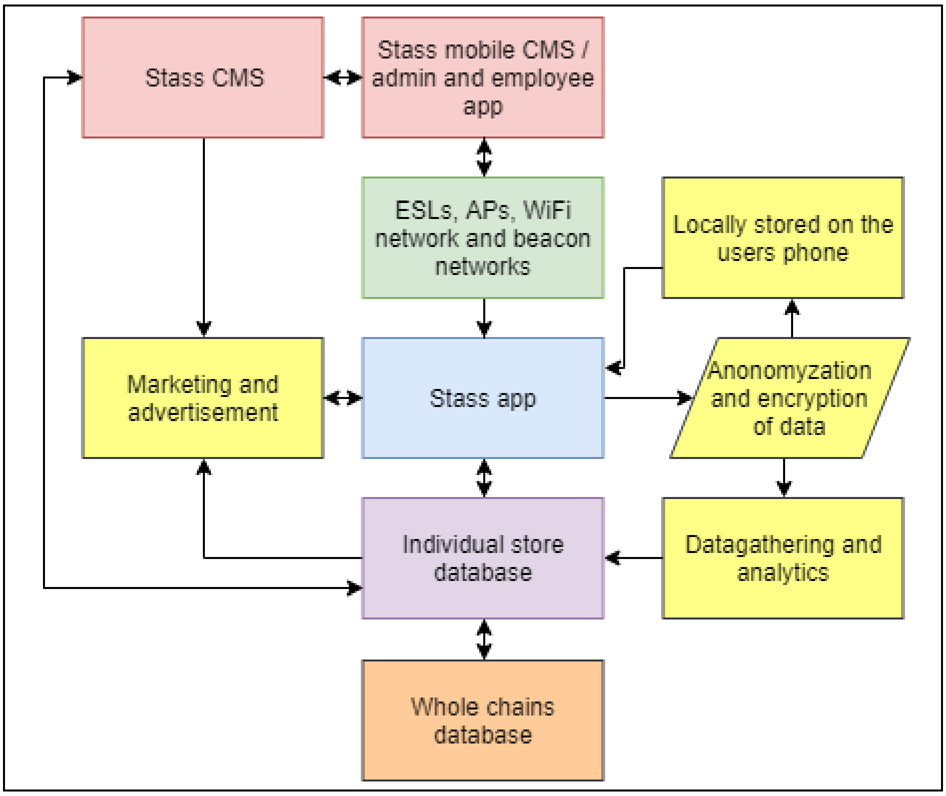


Figure 5.1: Image that portrays how the parts of Stass could work together

5.3 Android app

In this section we will look at and discuss some screenshots from the app.

5.3.1 Welcome and splash screen

Figure 5.2 shows screenshots of the Stass app, the splashscreen/loading screen that the user sees while Stass looks for beacons and checks if the ID the beacon broadcasts are in the database. On the right side we see the welcome-screen which shows the user information about the store that he has entered. An idea here is also that the loading screen is skipped, if the user allows background scanning for beacons. What happens then is that when the app sees a beacon while in background-scanning mode, it searches in the database and if it is very likely that a user is at the store the app shows a notification asking if the user wants to get assistance with Stass. If the user answers yes, he is taken straight to the welcome-screen. If the user answers no and opens up Stass later he will have to go through the splash screen. Deciding whether it is likely or not that the user is at the Store is in this project done by checking the user's GPS-location, and comparing it towards the GPS-location that the store is located. The user is presented with different actions to get assistance in the welcome-screen.

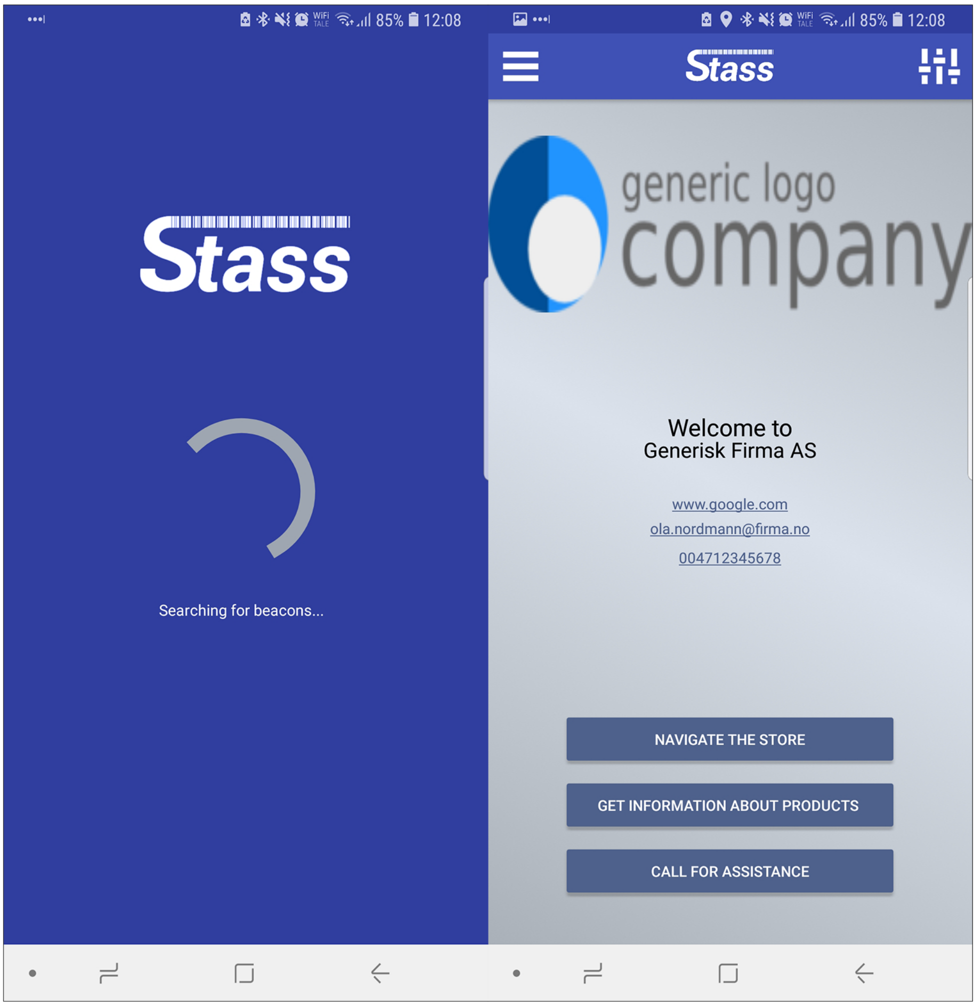


Figure 5.2: The loading screen and welcome screen in the Stass app

5.3.2 Nearby products

As the user moves around the store, the smartphone will pick up signals from different beacons, depending on where the user is. Figure 5.3 shows a list of products, which is in the Nearby Products-part of the application. From there the user can click a product and chose to get information on it, navigate to it or add it to the shopping list. In this project the products are associated with beacons in FireStore, and when a beacon is seen the user is simply presented with all products associated with the beacon. That is fine for a proof of concept app, and for demonstrative purposes. In the real world the nearby products should either be presented by finding the users position within the store, or one could do proximity-based association with beacons like in this project. If the proximity solution is selected, I would recommend having a restriction on distance (can be set by user) or make sure that the user isn't presented with information about products that is far away. Some beacons have a theoretical distance of over a hundred meters, thus simply associating products with beacons and presenting the products without further ado seems insufficient.

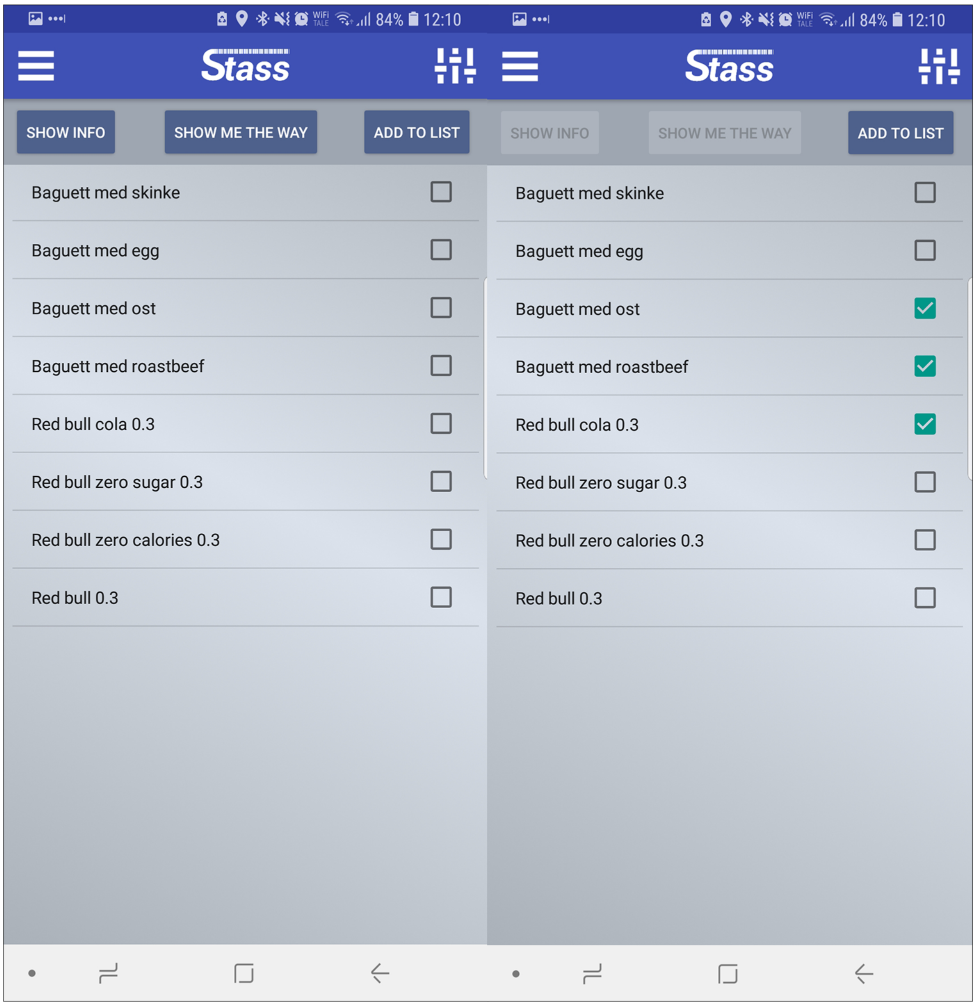


Figure 5.3: The list of nearby products, with some actions based on selections

5.3.3 Barcode scanner

When the user can't seem to find the information otherwise, an approach to assist the customer is to let the user scan the barcode of the product as seen in figure 5.4. One could here also use image recognition to try to recognize the product. When the barcode is scanned the user is asked whether the correct code has been detected or not, as barcode scanning didn't seem 100% accurate during development. If the user confirms, the app goes on to search in the FireStore database for the store the user is in, looking for products matching that barcode. In the scenario that one has multiple stores connected to the Stass-system, and the product is not found in the store the user is currently in, one could potentially check the other stores and let the user know if the product is available within a reasonable distance from the store.

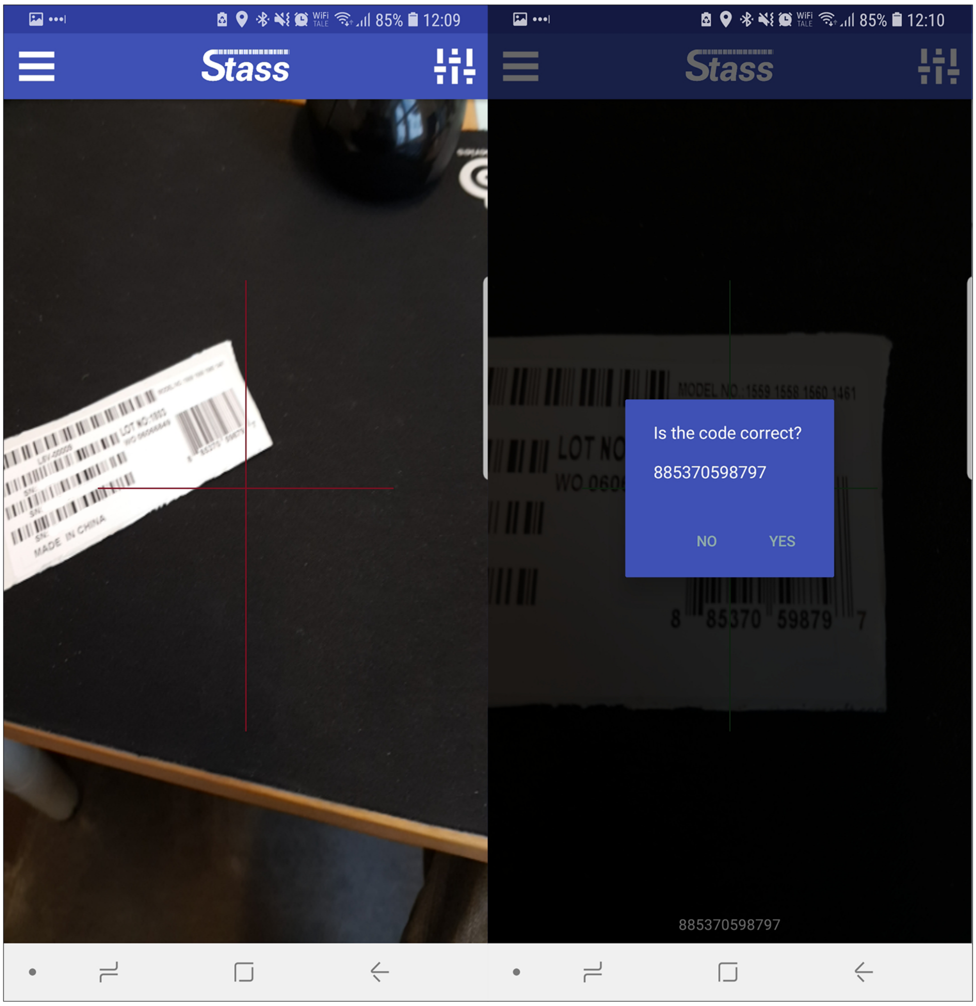


Figure 5.4: How it looks when the user wants to get information by scanning the barcode

5.3.4 Product information

Figure 5.5 shows the options the user is presented with to find product information, on the right one sees what it looks like when a product is found and presented to the user. Since this app is for demonstration purposes and is a proof of concept, the product information is merely a WebView in Android, meaning it displays a website. In the database each product is associated with an URL, so that if we need to present information about it we just show them the website with information about the product. The websites that the URLs are borrowed from in this project is *kolonial.no* and *nettbutikk.spar.no*. The idea is possible to build onto, when showing the user information about the product it is necessary with a visually pleasing, easy to read and straightforward presentation. It could be solved in a similar fashion, but rather point to the stores own online version, with an optimized layout. The search functionality allows the user to search for any product that is associated with the stores database of products, and the idea was that if no matches were found for the product in the current store the user were in, Stass would then apply the search to any stores nearby in order to give the user an option.

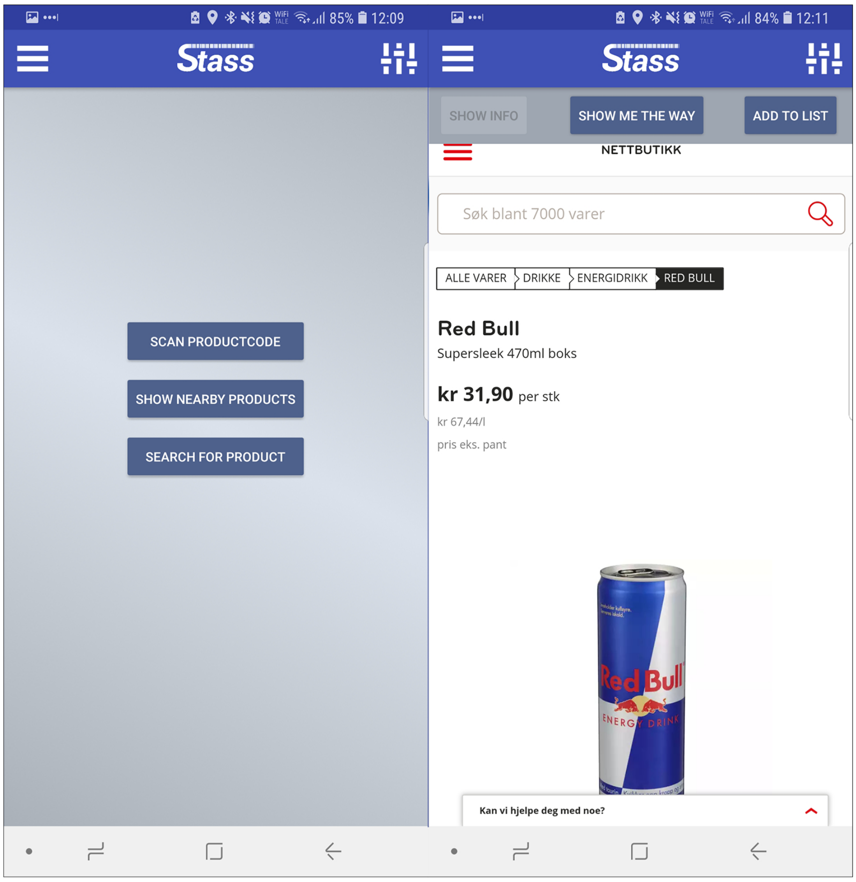


Figure 5.5: The product information, and how the user can find it

5.3.5 Shopping-list and product pathfinding

A very simple shopping-list is shown in figure 5.6, containing the products the user has added to his list. In the database, both the products and the beacons have location information as x and y coordinates. The beacons are more general and covers larger areas, and is therefore in bounds from one x,y point to another x,y point. The products are in a specific shelf and therefore the coordinate is one precise x,y point. This is in a proof of concept fashion but illustrates the point and potential. On the right part one sees a weird shape, which is supposed to portray a floor-plan/visual representation/layout of a store. The black parts are shelves and non-walkable areas, the green dot on the lower right is a hard-coded starting position for the layout and is set at the entrance. The red dot is also hard-coded end position at the exit after the checkout area. The orange dots represent the actual products, and are retrieved from the database. The green parts are the path-finding algorithm's answer, be although vary, the path is not optimal. It turned out that in this proof of concept built, the path-finding finding the most optimal path used more time than was bothered presenting to people. For demonstrative purposes I therefore rather went with the quickest solution that "does the job", it is greedy in the sense that it always chooses the next tile that is closes to the target. The flaw is that it doesn't take into consideration the obstacles, so if it encounters one it simply walks around. As one might notice the path isn't optimal if it were to be used for actual navigation. The idea is although that these maps comes in form of for instance Google's indoor maps as we saw for Ikea Round Rock in chapter 3.4's section 3.4.6. Therefore, the path finding would also be integrated in the Google Map service, however for demonstrative purposes this was fine. As the map was just for demonstrations, it did not offer any RTLS features or the ability to move or walk. It was simply a visual presentation of the store, path and products, with the input variables being what products to navigate to, and the path generated accordingly.

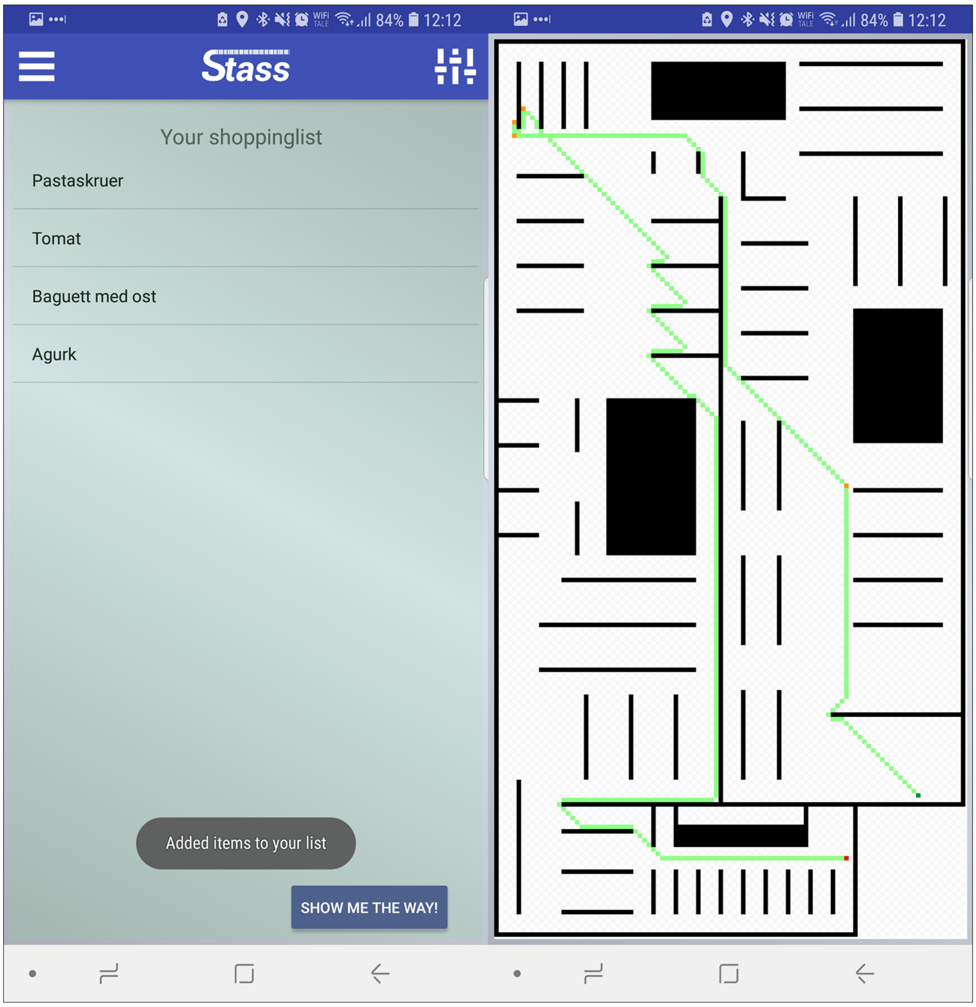


Figure 5.6: The shopping list in a simple form, and a view presenting the path prototype

5.3.6 Not implemented

The CloudQueue had its own activity, but was a hard-coded and not functioning implementation that were only used to demonstrate to the participants of the survey. Consisted of a number showing the position in the queue, the estimated time to wait and a button to push if assistance is not needed anymore. The implementation would although be fairly simple, but it came down to a matter of time.

As mentioned in subsection 5.3.5 the RTLS and IPS functionality of the system were not implemented, neither was the admin/staff part and CMS. Stass is a proof of concept app, with some of the features that one would expect to see in such an app.

6 Performance testing

In this chapter details concerning the data collection through testing the beacons performance is presented. How the testing took place, why it is helpful and details about the processes involved. The data found will be presented, discussion of the findings, and analysis of the data.

6.0.1 Purpose of the experiment

The aim of the performance testing is to answer whether BLE beacons have matured enough as a technology to be utilized alone as the location, data and context provider for systems like Stass. RQ1 asks: *"Does BLE beacons provide sufficient technological basis for micro-location and micro-positioning in retail stores?"*, answering the question is what the main goal of the experiment is. Additionally, the experiment allows this project to build upon the work of Saetre (2017) and Godoy (2017), and investigate if there are improvements to be seen as this project uses updated technology. The updated technology is in terms of a newer smartphone as well as three of the same beacons they had (but with newer hard and software), and four of the beacons that also come with UWB.

6.0.2 Venue of the experiment

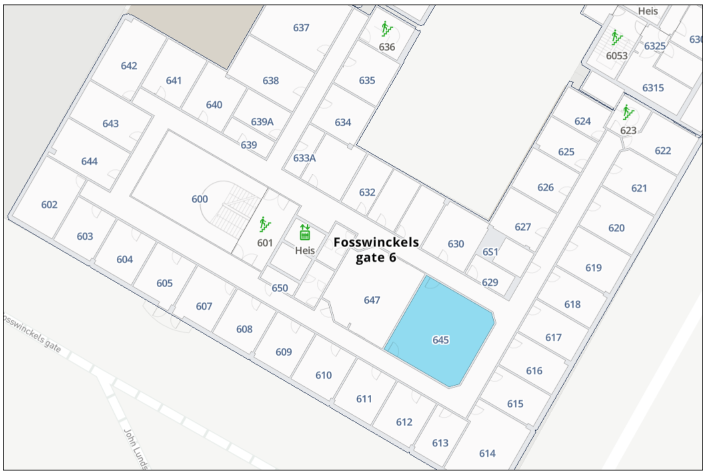


Figure 6.1: An overview from MazeMap of the floor where the tests were conducted

The testing was conducted on campus, the layout of the whole floor is presented in figure 6.1. Figure 6.2 shows the measurements that were done, which can be used to say something when looking at the data that is generated in this experiment. It was measured on a checkpoint, which line up with the marker and beacon on the wall. The path goes in between the beacon and marker, approximately 0.7 meter from the wall. So, a checkpoint are the place on the path, where the phone is closest to the beacon. One important thing to note is that although these measurements were accurate when measuring, they will be regarded as "correct", but are in fact not likely to be 100% at all times throughout the performance testing. Distance D shows that it was about 1.3 meters from the phone to the beacon, from the checkpoint. So, if the estimated distance based on the beacon signal tells us we're 1.20 meters away when at the checkpoint, it indicates that it thinks the phone is 10 centimeters closer to the beacon than it really is.

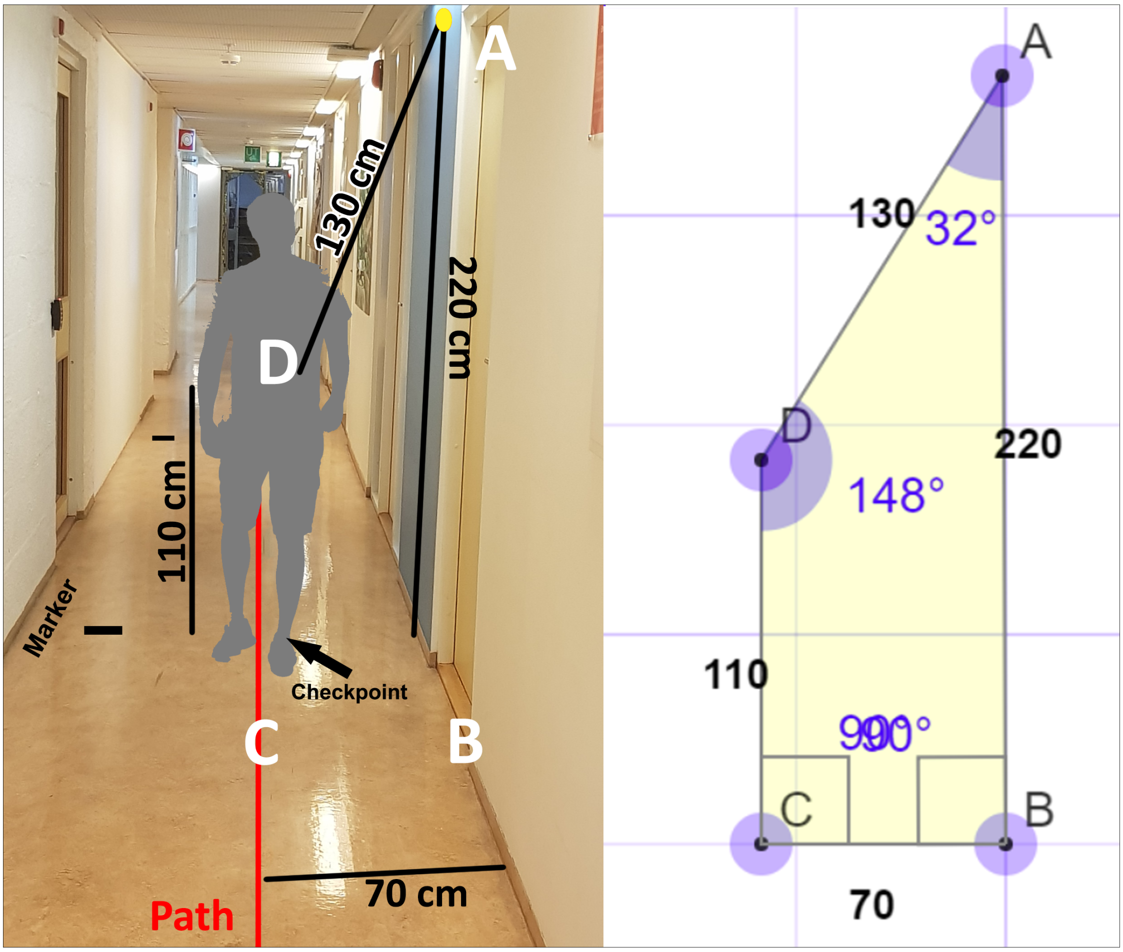


Figure 6.2: Illustration showing the measurements at the point closest to the beacon

6.0.3 Differences from the predecessors testing

The experiment was conducted and planned on the foundation that is in chapter 5 in the theses of Saetre (2017); Godoy (2017), there were however multiple differences.

Some similarities are that an Android app was the user interface and control panel for the testing, the data was uploaded directly to FireBase and the same company manufactured the beacons. That a newer smartphone, and newer and more beacons are used has been mentioned, and that the initial idea was to also use the Estimote SDK in the testing. It ended up being AltBeacon's SDK that were utilized instead, due to the problems mentioned in subsection 4.4.1. A list that summarizes the differences:

1. Newer smartphone
2. New and better beacons
3. More consistent SDK
4. Data types are changed (the monitoring events and ranging events are disregarded)
5. More data collected (steps, distance, speed)
6. Beacons are placed on the walls, which is a more likely scenario in a store

The monitoring events are dropped because it only gives the answer to whether we received a signal from the beacon, while ranging looks at the actual signal, therefore monitoring events are unnecessary to include. The 'ranging events' were just a custom workaround they made because the monitoring was broken, so the ranging events are not necessary either. To get some comparable data, a sample of tests were conducted after their descriptions. It targeted the setting of 10 meter distance between the beacons, with -16 dBm broadcasting power and 100 ms advertising interval, it is covered in section 6.3.

6.0.4 Tools used for the data collection

The beacons, a smartphone and an app were the main tools. Accompanied by a database and some software libraries. Details on the respective tools can be found in chapter 4 on development of the artifact and experiments.

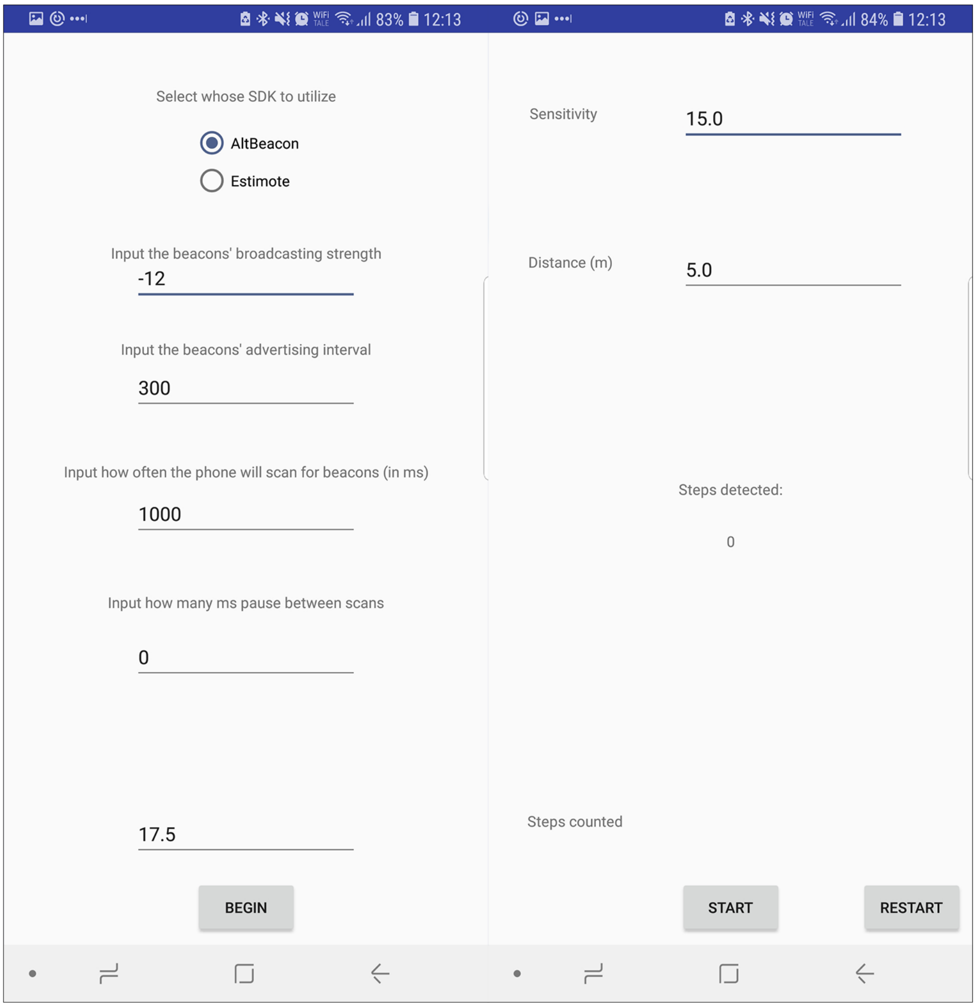


Figure 6.3: The settings page for the data gathering sessions (beacons and steps)

Figure 6.3 shows the GUI for the performance testing and step calibration. On the left screen, which is for the performance testing of the beacons one finds some settings that were never touched: the SDK options, phone scan milliseconds and phone scan pause milliseconds. The value in the left screen on the bottom that says 17.5 is the input for the sensitivity setting, in the tests it was always set to 15.25 (as it was found to be the most accurate setting). The settings that were changed were the beacons broadcasting strength and advertisement interval, which were adjusted accordingly to the settings on the beacons. On the right screen for the step calibration, the sensitivity to be tested is input and the distance to be walked. When the step session is done it requires a human input for amount of steps taken, before it can be uploaded to the database.

6.1 Step calibration

In this section the step calibration and the findings are presented. The entry that is generated each time a recording is done can be seen in figure 6.4, 160 such entries served as the data for the StepCalibration. aSteps is the steps that the app counted, mSteps is the manually counted steps.

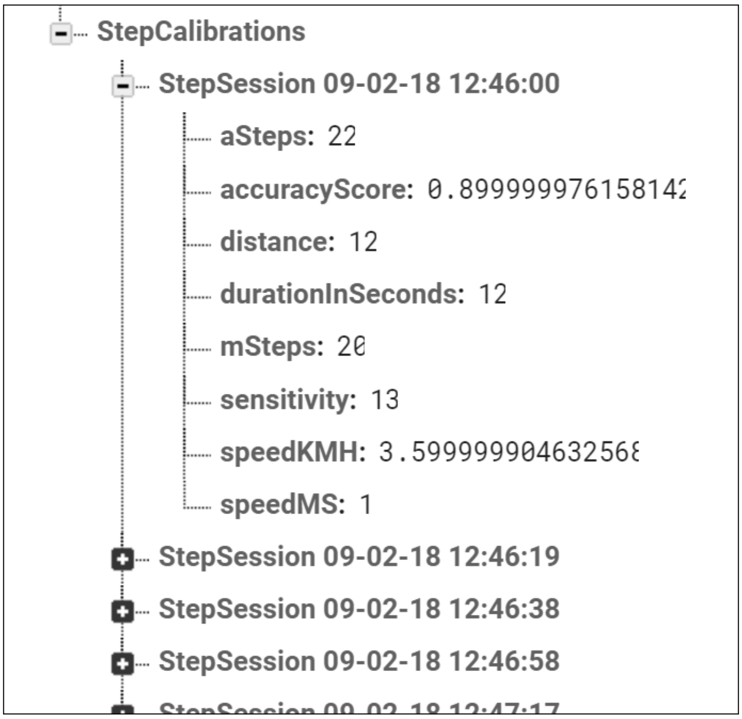


Figure 6.4: What a StepCalibration session object looks like in FireBase

6.1.1 Step calibration environment and parameters

The StepCalibration was needed so that the data from the inertial sensors would be as accurate as possible. During the experiment the phone would be in the hand, not in the pocket. Ensuring the most optimal counting of steps were crucial, if data about the walking were to be included. The way this was done was by creating an activity in the Android app, that was separate from Stass' actual functionality. The input was sensitivity setting and distance to be walked (measured on forehand), the sensitivity setting early became obvious that needed to be somewhere between 10-20 (after doing some initial tests), which reduced the amount of tests needed. Data available the consisted of:

- Distance walked in meters

- Manually counted steps
- App-counted steps
- Sensitivity setting for app-counted steps
- Duration

The data was stored in a FireBase database in JSON format, from the collected data some additional data was generated and included in the stored JSON object. These consisted of:

- Accuracy score (difference between steps manually counted and app-counted)
- Average km/h and average m/s
- SessionID consisting of a time-stamp

6.1.2 The step calibration recording sessions

When everything was planned out, the next step was to record the sessions. When all the sessions were conducted, it was time to compare the sessions by creating a simple Python-script which retrieved all the sessions and calculated which was the most accurate. Additionally, it also created graphs illustrating the difference in counted steps for each individual recording.

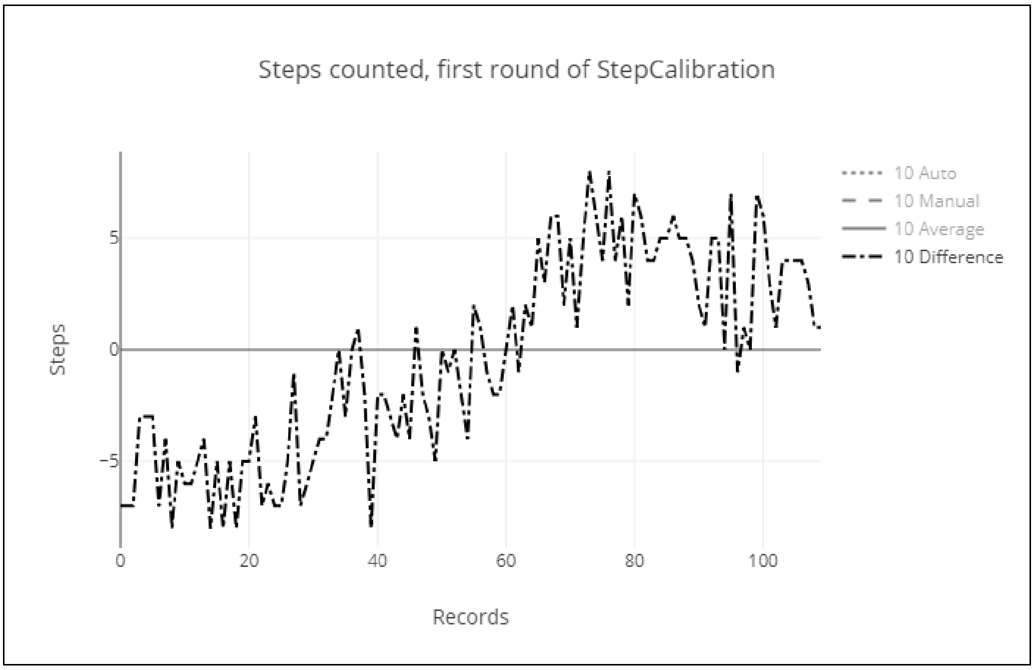
The tables in this subsection shows the values of the average accuracy and difference in counted steps, the ideal average accuracy is 1.0 and the ideal difference in counted steps is 0. To get an accuracy of 1.0 and step difference of 0.0, the sensitivity setting would have to provide the correct amount of steps each time, the correct amount then being the same as I counted. An accuracy value below 1.0 means it counted too few steps, while above means that it counted too many. To find the difference in counted steps, the absolute values are added together and then divided by the amount of sessions. The reason the absolute values are needed is because if it in one session detected three steps too few and the next three steps too many, it would give the average difference of zero rather than three. Which is also the reason both the average accuracy and difference in counted steps are included, the winning sensitivity might not be the best in both categories (averagely miscounted steps and average accuracy).

Round 1
Ten recordings were created for all integers from 10 - 20, each recording being 10 meters in distance, at the end of recording them all the script was executed to see which scored best. Graph 6.1 shows all the recordings, and the difference in counted steps for each. It increased incrementally, so that 0-10 is the setting 10, 10-20 is the setting 11, 20-30 is 12 and so forth. The horizontal line is 0 difference, so the closer to the horizontal line the more accurate the recording is. Recordings 50-60 (setting 15) is the area where it stays closest to the horizontal line. Table 6.1 shows the results, also deeming 15 as the

setting that scored best. It averagely miscounted 2.1 steps and had an accuracy score of 0.953, it won as it were best in both categories.

The first round of StepCalibration						
Sensitivity values	10	11	12	13	14	
Avg. accuracy	0.749	0.726	0.751	0.872	0.867	
Avg. diff count of steps	6.4	7.0	6.4	3.7	3.6	
Sensitivity values	15	16	17	18	19	20
Avg. accuracy	0.953	1.220	1.452	1.443	1.241	1.244
Avg. diff count of steps	2.1	2.2	3.9	4.1	2.5	2.1

Table 6.1: The results for the the first round of step calibration



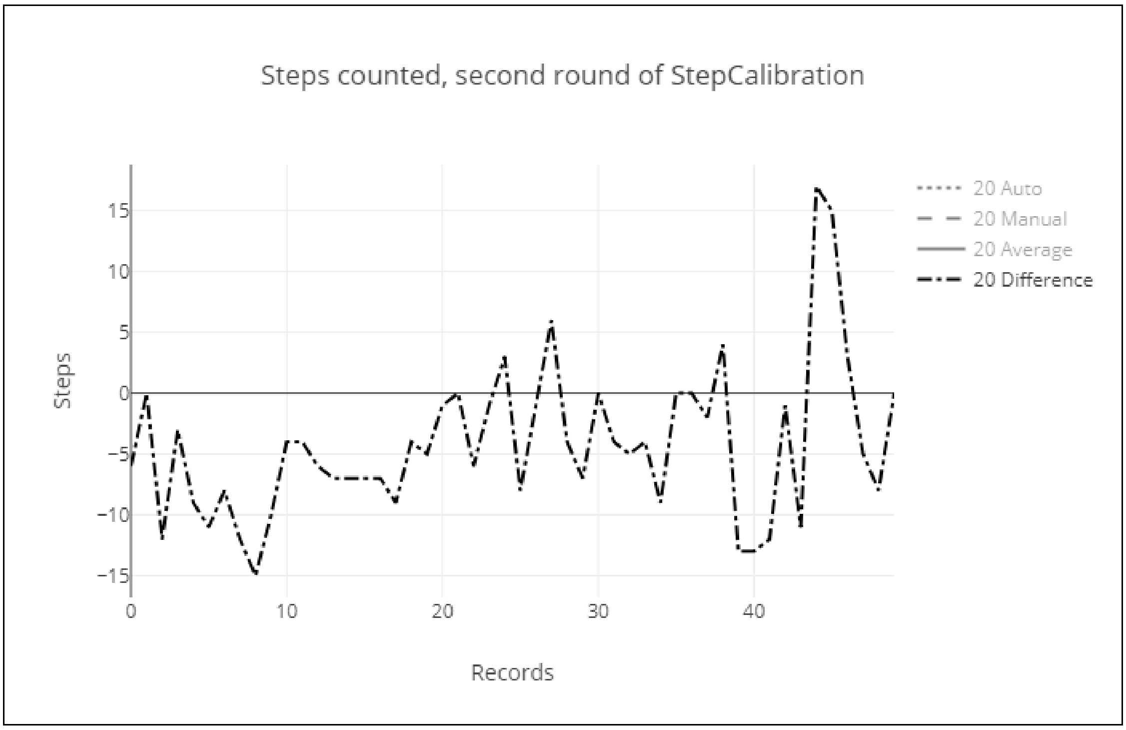
Graph 6.1: The difference in counted steps for each recording in the first round

Round 2

The next step was to do some more testing on the number 15.0 and some of the closest alternatives. Further tests on the winner and some deviation were conducted, as a way to make sure the right number would be the final sensitivity setting. Although this time we selected floating numbers, as 15.0 was the winner, the settings to be tested would be 14.50, 14.75, 15.0, 15.25, 15.50. This time with 10 recordings with an increased distance of 20 meters, the distance was increased to get more data and thus increase the accuracy. Graph 6.2 shows the difference in counted steps per recording, the horizontal line represents 0 in this graph as well. 20-30 is the setting 15.0 and 30-40 is 15.25, and this is clearly the range that is most accurate. 15.25 counted correctly twice and were usually close except one large outlier at the end, but it is hard to clearly state a winner. Similarly, the results in table 6.2 also shows the winner being not as clear. 15.0 won the average, but 15.25 turned out to have almost one less counted step on average (even with that one large outlier). As mentioned the average doesn't account for the too many/too few problem, and 15.25's accuracy was almost as close as 15.0's even with the outlier. Therefore 15.25 were ultimately selected as the winning sensitivity to be used for the actual performance testing.

The second round of StepCalibration					
Sensitivity values	14.50	14.75	15.0	15.25	15.50
Avg. accuracy	0.787	0.834	0.953	0.945	1.062
Avg. diff count of steps	9.6	7.0	4.3	3.6	10.2

Table 6.2: The results for the the second round of recordings



Graph 6.2: The difference in counted steps for each recording in the second round

6.1.3 Results

The winning sensitivity setting were 15.25, the average speed from the step calibration sessions were 3.93 km/h (1.09 m/s) and the average length of my step were 0.64 meter. These variables were then stored in the StepData seen in subsection 4.6.2, later used as input to gather additional data in the performance testing. The numbers might not be 100% accurate, but they are gathered in a manner that seems more than sufficient for use in the performance testing.

6.2 Beacon performance testing

This section covers the beacon performance testing. It contains details around the circumstances and environment and should together with the rest of the chapter contain sufficient information for understanding and recreating the experiment. At the end, some of the data found is presented and discussed.

6.2.1 The beacon performance graphical user interface

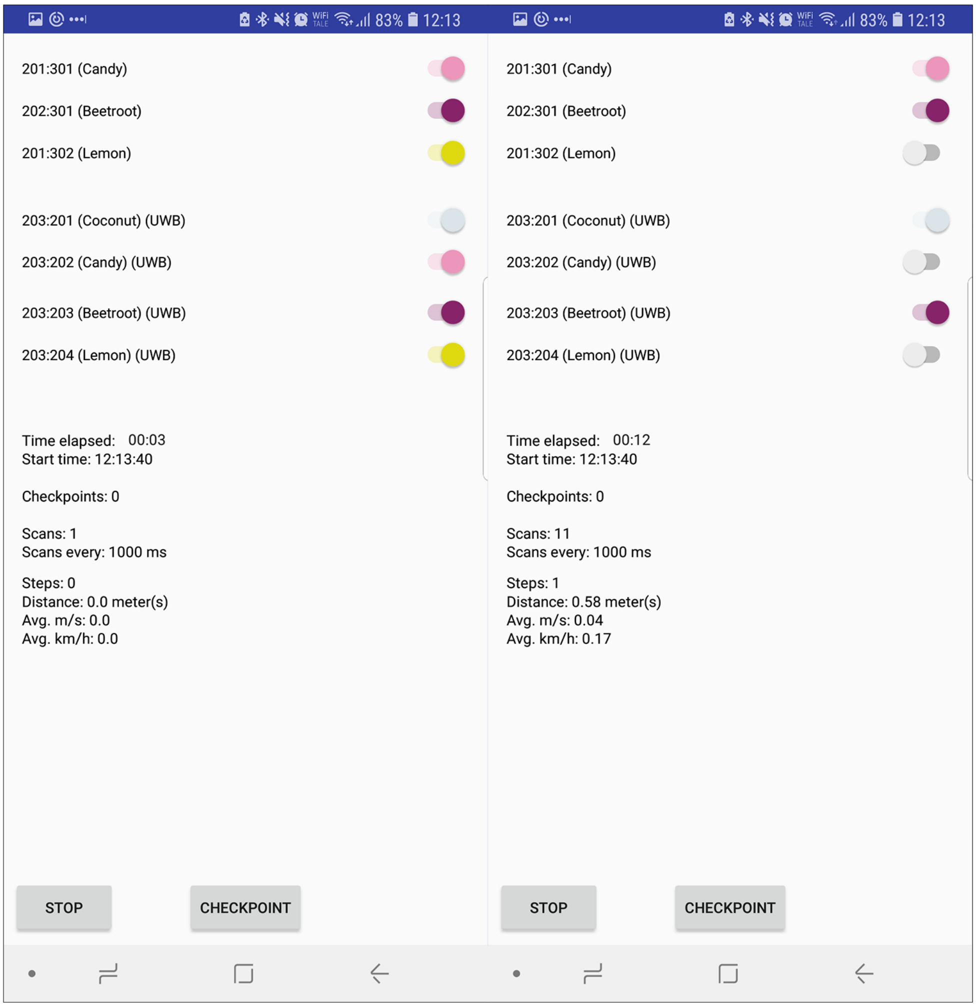


Figure 6.5: The data gathering view for the testing of beacon performance

6.2.2 Testing environment and parameters

The variables broadcasting power (dBm) and advertisement intervals (ms) is the different settings that are changed for the beacons, and there were two kinds of tests; one with 5 meter between the beacons, and one with 2.5 meter between the beacons. The approximate positions of the beacons can be seen in figures 6.7 and 6.6, note that also the order of the beacon is the same, the pink beacon with UWB is the first beacon in the path and the purple beacon with UWB is the last. The settings of the beacons were -16 and -20 dBm in broadcasting power, and 100 ms and 950 ms for advertisement interval. The intervals were the same as used by Saetre (2017); Godoy (2017) and the -16 dBm as well, their other dBM setting were -0 dBm. In their table showing the signal strength and approximate radius, it shows that -16 dBm translates to a radius of approximately 7 meters, and for 0 dBm 50 meters (Saetre, 2017; Godoy, 2017). In this testing the 50 meters didn't seem as relevant, -16 dBm / 7 meters initially seemed like a setting that could be usable, and -20 dBm (for which the table shows 3.5 meters) seemed more appropriate for instance for the nearby products based on seen beacons, therefore -20 dBm were chosen as the second broadcasting power setting. This left us with two different distances between the beacons, two different broadcasting powers and two different intervals. To test all of them with each other, a total of eight tests settings needed to be tested, as seen in table 6.3. For each of the eight settings, 10 recordings/sessions were performed, which ultimately resulted in 80 sessions in the database.

The different settings for the testing, and what sessions they were conducted			
Meters	dBm	ms	Sessions
5	-20	950	1-10
5	-20	100	11-20
5	-16	100	21-30
5	-16	950	31-40
2.5	-16	950	41-50
2.5	-16	100	51-60
2.5	-20	100	61-70
2.5	-20	95+	71-80

Table 6.3: The different settings used for the beacon performance testing

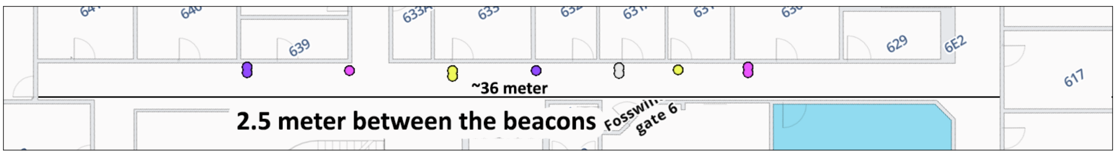


Figure 6.6: The approximate placement for the beacons in the 2.5 meter tests

In figure 6.7 the entry and exit paths came from the side corridors, as to not start on

Figure 6.7: The approximate placement for the beacons in the 5 meter tests

top of a beacon. Saetre (2017); Godoy (2017) mentioned that they started each test outside the range of the beacons, which is favorable when attempting to collect these kinds of data. A small and cleaned part of the JSON file containing data about the BeaconPerformance structure looks like this:


```
{
  "BeaconPerformance" : {
    "13-05-18" : {
      "12:36:04" : {
        "beaconSettings" : {
          "advertisingIntervalms" : 950,
          "broadcastingPowerdbm" : -20
        }
          ...{scanNumbers: 0,1,2},...
        {
          "checkPoints" : 0,
          "currentScanMillis" : 932029595313125,
          "currentScanString" : "12:36:08",
          "currentavgSpeedKMH" : 2.869999885559082,
          "currentavgSpeedMpS" : 0.7900000214576721,
          "distanceWalked" : 3.1999998092651367,
          "scanNumber" : 3,
          "scanObjectID" : "Scan:3-12:36:04",
          "stepsTaken" : 5
        }, {
          "beaconsSeen" : {
            "b9407f30-f5f8-466e-aff9-25556b57fe6d:203:202" : {
              "beaconTypeCode" : 533,
              "bluetoothAddress" : "E3:F8:C6:7C:10:2A",
              "distance" : 1.3362612968653254,
              "manufacturer" : 76,
              "multiFrameBeacon" : false,
              "rssi" : -93,
              "runningAverageRssi" : -93,
              "serviceUuid" : -1,
              "txPower" : -85
            }
          },
```


Code snippet 6.1: Cleaned JSON snippet from the BeaconPerformance database

Showing coordinates for markers in 3D					
X = Length, Y = Width, Z = Height					
Position	X - 5m tests	X - 2.5 m tests	Y	Z	Adjacent beacon
1	0.0	0.0	1.3 m	0.0 m	Pink UWB (203:202)
2	5.0	2.5	1.3 m	0.0 m	Yellow (201:302)
3	10.0	5.0	1.3 m	0.0 m	White UWB (203:201)
4	15.0	7.5	1.3 m	0.0 m	Purple (202:301)
5	20.0	10.0	1.3 m	0.0 m	Yellow UWB (203:204)
6	25.0	12.5	1.3 m	0.0 m	Pink (201:301)
7	30.0	15.0	1.3 m	0.0 m	Purple UWB (203:203)

Table 6.4: Positions in 3D for the markers, both 5 and 2.5 m tests

Showing coordinates for beacons in 3D					
X = Length, Y = Width, Z = Height					
Beacon	Position	X - 5m tests	X - 2.5 m tests	Y	Z
Pink UWB (203:202)	1	0.0	0.0	0.0 m	2.2 m
Yellow (201:302)	2	5.0	2.5	0.0 m	2.2 m
White UWB (203:201)	3	10.0	5.0	0.0 m	2.2 m
Purple (202:301)	4	15.0	7.5	0.0 m	2.2 m
Yellow UWB (203:204)	5	20.0	10.0	0.0 m	2.2 m
Pink (201:301)	6	25.0	12.5	0.0 m	2.2 m
Purple UWB (203:203)	7	30.0	15.0	0.0 m	2.2 m

Table 6.5: Positions in 3D for the beacons, both 5 and 2.5 m tests

Tables 6.4 and 6.5 shows the XYZ coordinates for the beacons and the markers on the ground, given that X:0,Y:0,Z:0 is in the right lower corner adjacent to the first marker. As shown previously in figure 6.2, the path I walked were between the marker and the wall, it was measured to 0.7 meters from the wall. The height from the floor to where I held the phone were measured to 1.1 meter. Thus the position of the phone is X:n,Y:0.7,Z:1.1, n being wherever I am on the path at the time. Keep in mind that a checkpoint is different from a marker, the checkpoint is on the path, aligned with and between the marker and beacon. To illustrate, let's take an example scan where I just pushed the checkpoint button at the second checkpoint, in a 5 meter between beacons test-setup. The X value for the phone would then be the same as the X value for the second marker and adjacent beacon, which is 5.0 (first beacon is at 0.0, second at 5.0, third at 10.0). Figure 6.8 illustrates which axis is where, and what is considered point 0,0,0.

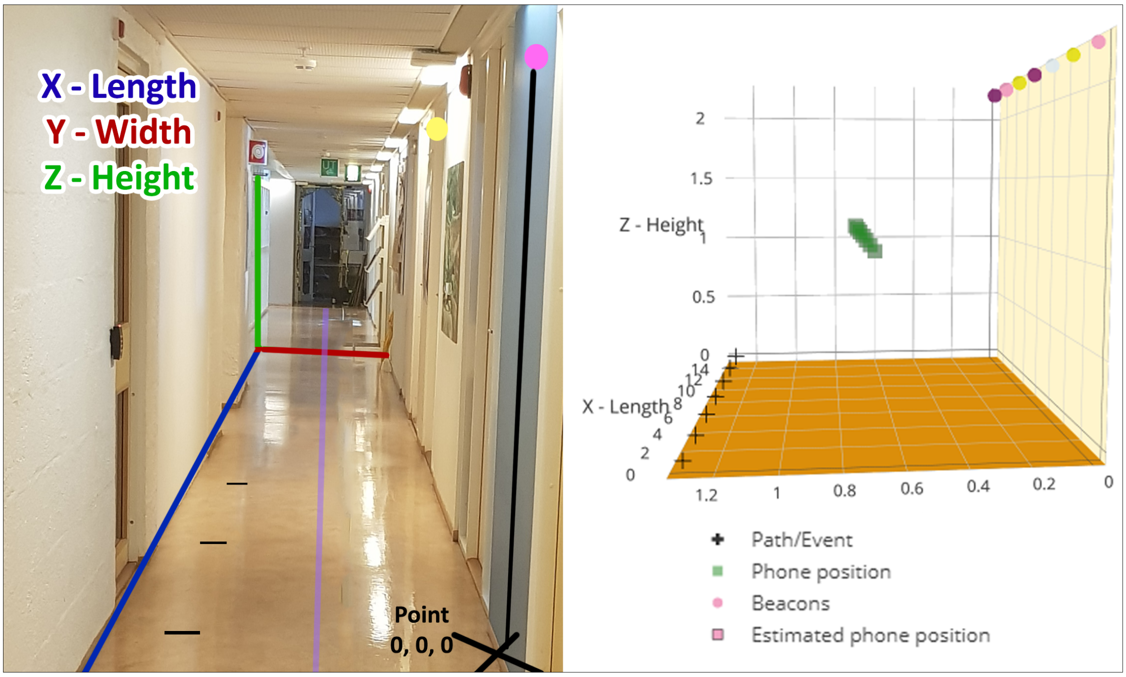


Figure 6.8: Illustration to provide context for the XYZ orientation and point 0,0,0

6.2.3 Finding information in the data

Using the signal received from the beacon, we get an estimated distance from the phone to the beacon from the AltBeacon SDK. The question then is how to find out how accurate it is? Here the way used to find information in the data in this experiment is explained.

To be able to compare the distance estimated made by the SDK, we must find the actual distance to the phone. Which is why everything was measured, beacon height on wall, distance between them, height from the floor to where I held the phone and more. With all these measurements, we can find the actual distance from the phone to the beacon.

Each checkpoint has an adjacent beacon that is about 1.3 meters away, as seen in figure 6.2. If one views the hallways in terms of a 3D space as seen in tables 6.5 and 6.4, the checkpoint lines up with beacon on the X-axis (Z is height, Y is width, and X is length). With this data, and the estimated distance to the beacon that is based on the signal from the beacons, we can calculate how much the estimation missed by.

What scans to look at?
A session consists of a scan each second, not all the scans actually received any signals from the beacons. For those scans who did, there are multiple ways to filter and consider different factors when looking at the data that were produced. For instance, one can

choose to only look at the scans which have a checkpoint event in them, as this is the only scan we know the actual X value (as I pushed the event when on the checkpoint). Once we look at a scan, we can then choose to only consider the beacon adjacent to the current/last checkpoint, or we can look at both the adjacent beacon and the beacons that for instance are adjacent to the closest checkpoints (the one behind, and the next checkpoint (+/- 1)). The two previous and the two next checkpoints make for +/-2 (offset of 2 beacons up and down), and it keeps going up to +/-6 which covers all the beacons. If also considering and looking at scans that are in between the checkpoints, the data from the step calibration comes in handy, as that data is used to estimate our position on the X axis.

What beacons to look at?
A scan might contain data from several beacons, but this might not always be favorable. The reason one might choose to look at different beacons are because of the inconsistencies one might find in the signals. If the scan one is looking at is at the second checkpoint, the distance between the beacons being 5 meter, and we get the signal from the beacon adjacent to the seventh checkpoint (five checkpoints away). In this scenario the beacon is 25 meters away and depending on the settings of the beacon the estimated distance might not be too good. As the signal possibly shouldn't have reached the phone at all, but perhaps did so due to signal being reflected and bouncing further than it should have.

What effect looking at different things has
What does this all come down to? Well, it comes down to while choosing which beacons to look at +/- 0 means we only look at the closest beacon which, while +/-6 is means we look at all the signals from all the beacons. If we only look at scans that are on checkpoints, we only get seven scans per sessions, but we do know the actual distance to all of the beacons. If we look at all of the scans we get between 20-50 depending on many factors, in that case when the scan is not at the checkpoint we have to estimate the X position of the phone.

The Pythagorean theorem is used to find the distance from the phone to the beacon, but we can only do so when we know the XYZ coordinates for both the phone and the beacon. Thus, when we are at the checkpoint and know all the coordinates, the distance we get to the beacon is very accurate.

What this means is that for the scans that are not on the checkpoints, the distance to the beacon is an estimation based on where the phone's X measure was estimated to. We estimate where the phone is, for instance based on my average speed for the session and use that estimation to calculate how far it is to the beacon.

Only looking at scans that have a checkpoint, and only looking at the adjacent beacon, which is the closest beacon is naturally what gives the least difference in estimated distance and actual distance. For each extra +/- offset, the difference increases.

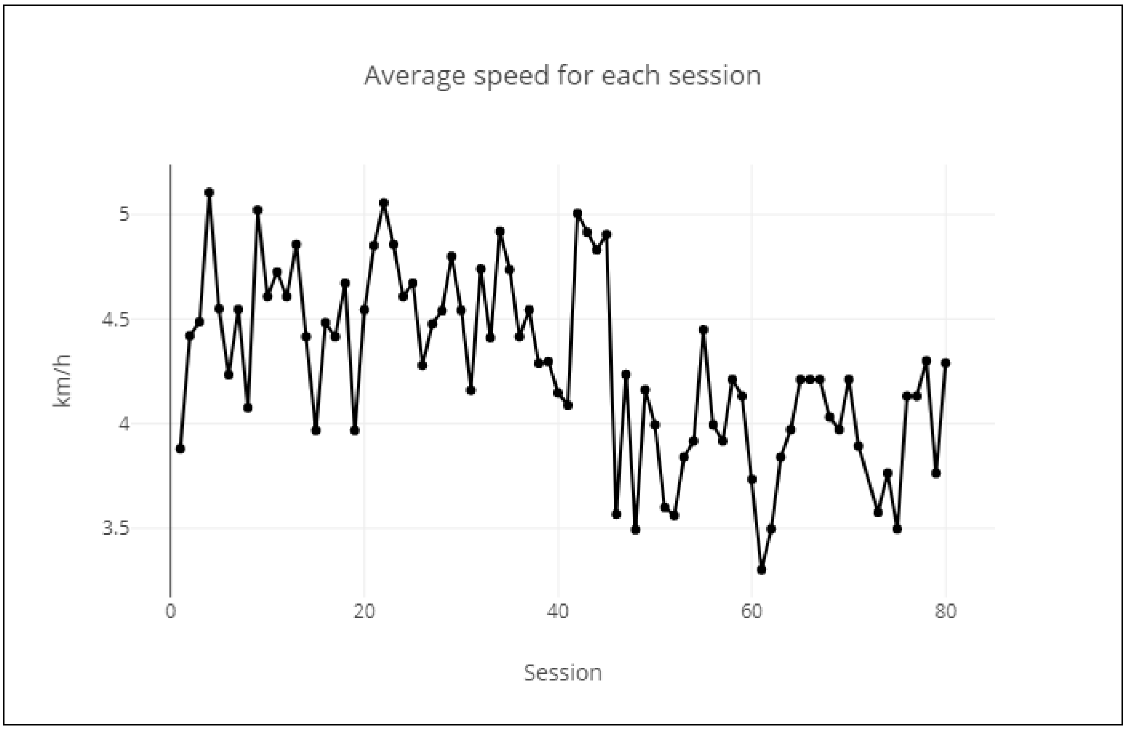
What is the accuracy

To find the accuracy, we take the distance to the phone calculated with Pythagoras and subtract the estimated distance to the phone based on the signal from the beacon. This gives a negative value when it estimation was too high, and a positive when it was too low. Instead of looking at whether it missed by too much or too little, we get the absolute value of the number and simply get the distance it missed by. Ultimately, this gives us: how many meters the estimation based on a beacon's signal missed by. The closer to 0 meter the estimation were, the more accurate.

6.2.4 Results

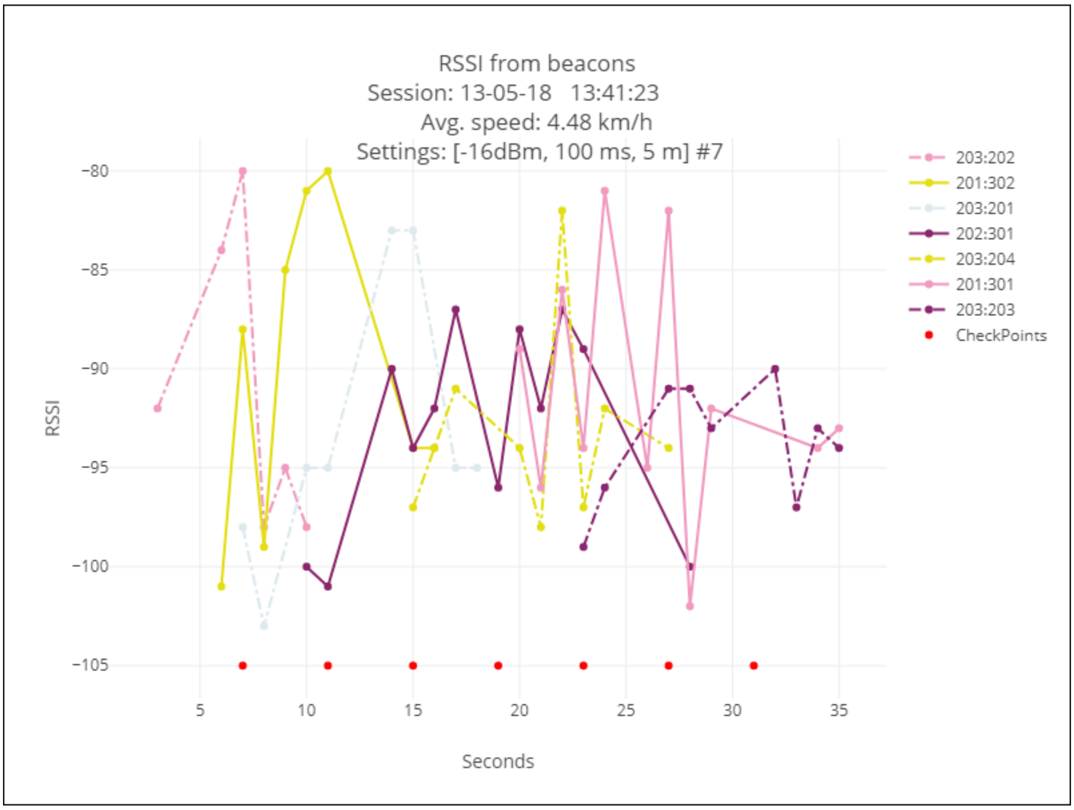
The testing created a JSON document of 170,000 lines, and around 5 megabytes. After cleaning away some non-essential pieces, it ended at around 75,000 and around 3 megabytes. The testing took about five hours, with setup and breaks. With the Step-Calibration and the predecessor comparability testing it took about 8-9 hours, and over 20000 steps. All the graphs for the individual sessions, can be found in Appendix B at section 11.1.

Graph 6.3 shows the average speed per session, there were a general drop in speed around the middle. After a break when the beacons had to be repositioned from the 5 meter to the 2.5 meter tests. The speed ranged from around 5 to 3.5 km/h, but were averagely around 4.5-4 km/h. The step calibration found that 3.93 km/h was my average, so around those speeds were expected. There are several ways to estimate the distance walked/the phones position on the X-axis when between the checkpoints. One approach is to multiply the steps counted by the average speed found in the step calibration, another is to multiply the steps counted by the average speed for the specific session. While creating the other graphs and visualization, when estimation of the phone's position on the X-axis had to be done based on data related to walking, the average of a couple different approaches were used as the estimation.



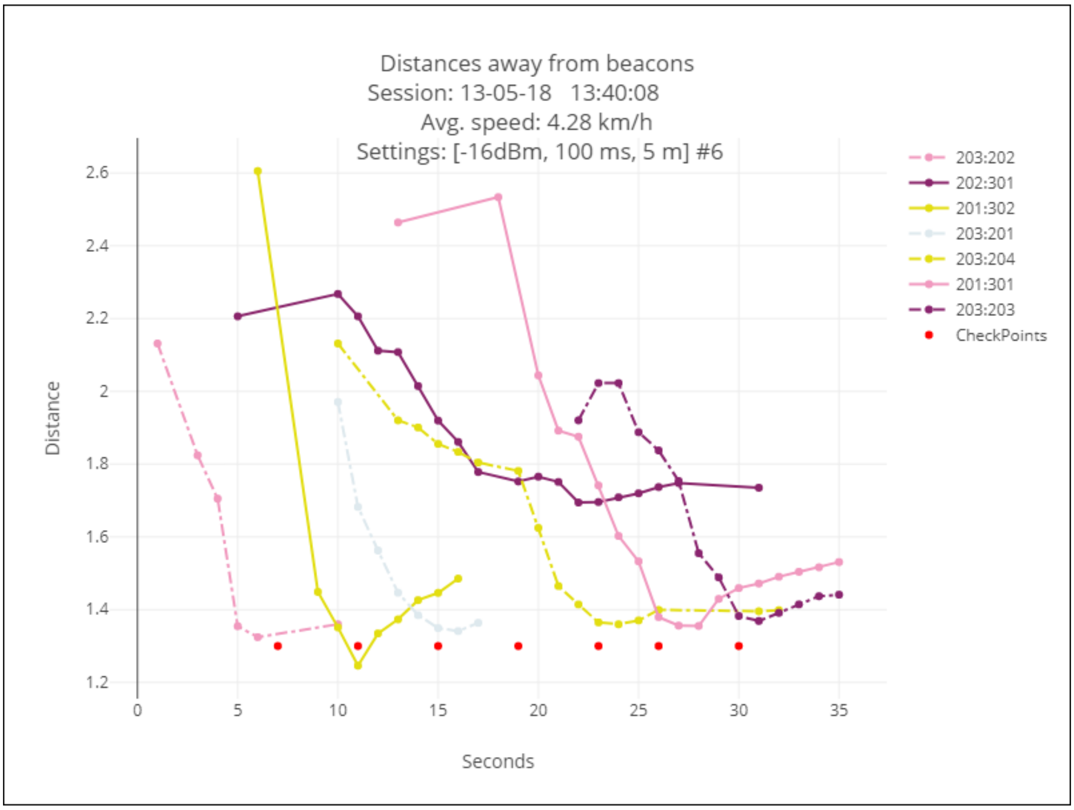
Graph 6.3: Graph that shows the average speed in km/h per session

Graph 6.4 shows the seventh session of the tests with the settings -16 dBm, 100 ms and 5 meter between beacons. The red dots are the points in time where I was walking past the checkpoint, the x-values are scans or seconds (one scan per second). The RSSI values are a bit all over the places within -80 to -105, to most people the values are not very meaningful. The RSSI values are one of the variables that the AltBeacon SDK use to estimate the distance from the phone to the beacon.

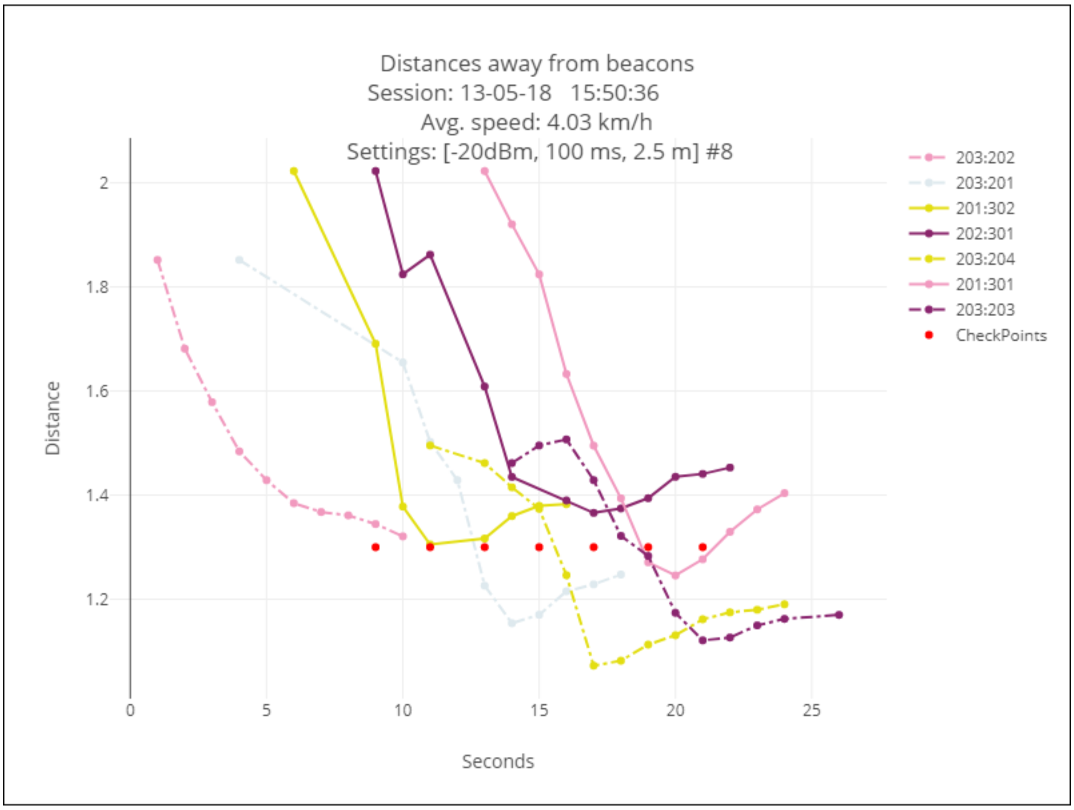


Graph 6.4: An example of the received signal strength indicators for a session

Graphs 6.5 and 6.6 show the estimated distances for each received signal from the beacons, the red dots are checkpoints and as seen in figure 6.2 when at the checkpoint the distance to the adjacent beacon is 1.3 meter. The order of the beacons are as illustrated in figure 6.7, which the graph to some degree indicate. Ideally, the traces would hit the red dots exactly, when at its lowest point in the graph. As the graphs show the signals are usually picked up before the checkpoint is reached, and the estimated distance drops until its lowest point around the checkpoint (which is the closest point). Therefor one can say that these two graphs do indicate how the movement were, and thus shows promise.

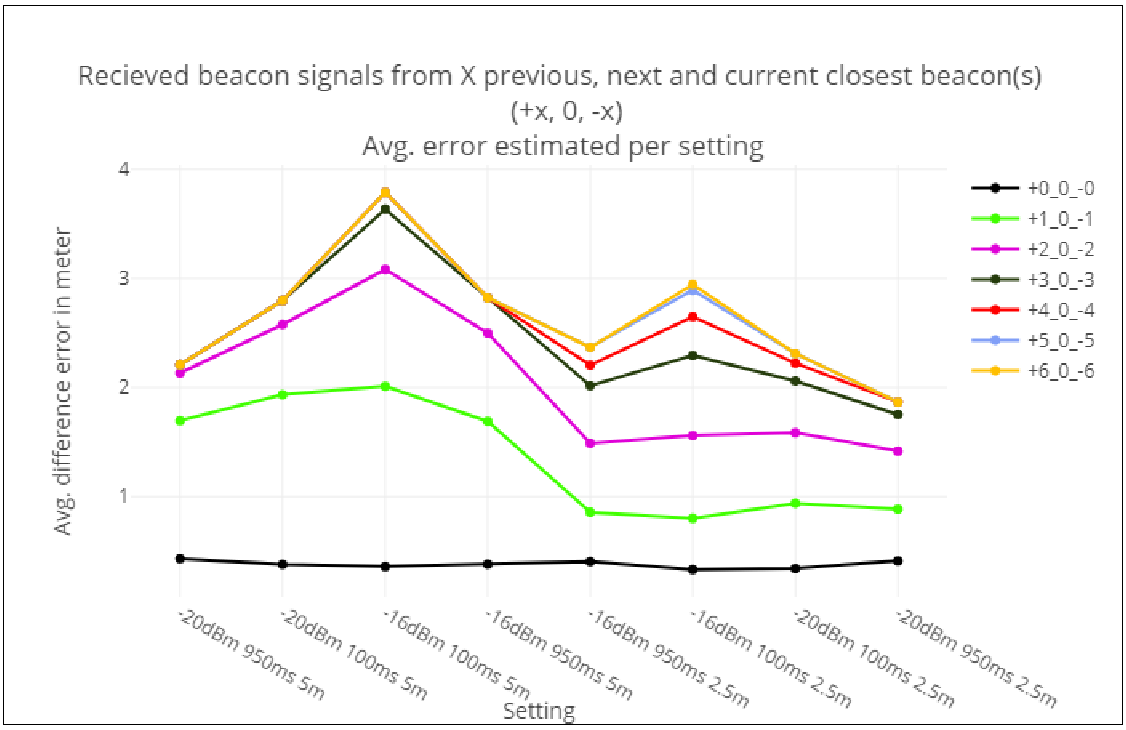


Graph 6.5: An example of the estimated distance throughout a session



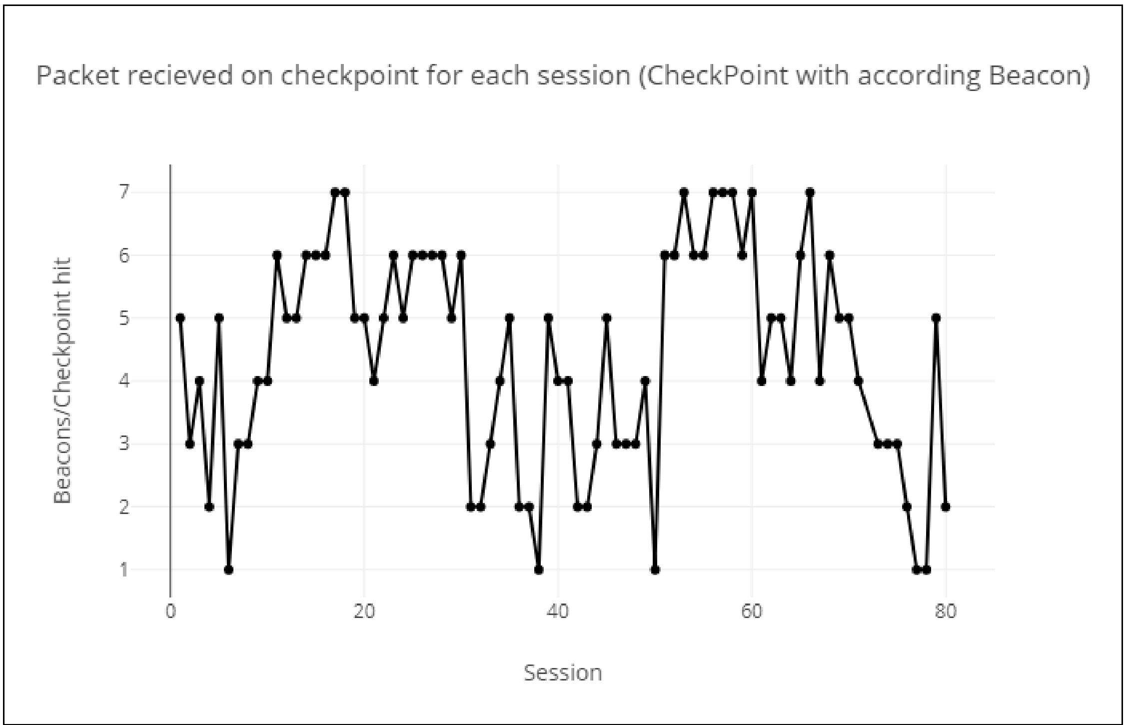
Graph 6.6: Another example of the estimated distance throughout a session

The graph 6.7 shows all of the different test settings, and for each it shows seven points which is the average difference in estimated meters, based on different offsets. As expected only looking at the beacons that is close to the checkpoints (+/-0) give high accuracy (varying from 0.45-0.30 meter), and the more beacons included the lower the accuracy becomes. When the offset is higher than three beacons, most of the signals are picked up so there isn't much difference. This looks alright in terms of proximity-based applications, not as much in terms of precision navigation.



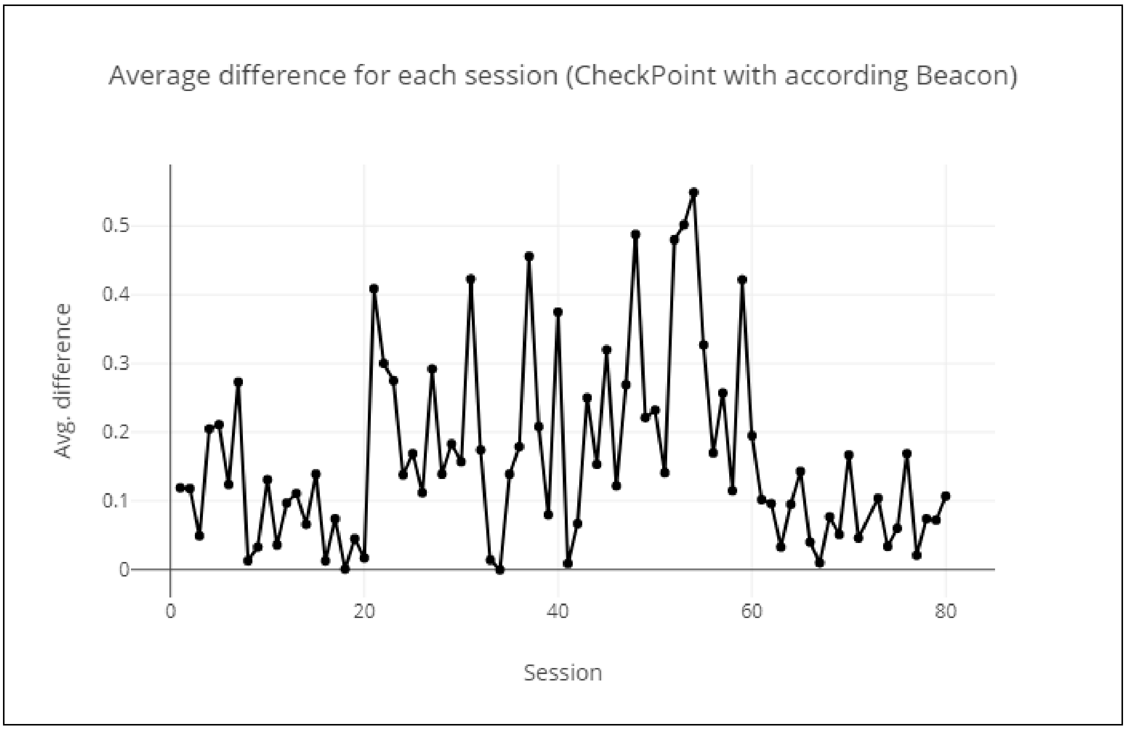
Graph 6.7: Difference in estimated vs. actual meters, per setting and offset

Graph 6.8 shows the packet "hit rate" for all the sessions, only considering the checkpoints. On the scans that are at the checkpoints, do we receive the signal from the beacon that is adjacent and closest to the checkpoint? Ideally, the trace would always be at 7 as one would expect to receive a signal from the beacon when it is 1.3 meters away. Especially since the setting of the beacon either have an approximate radius of 3.5 or 7 meters (depending on whether the setting is -20 or -16 dBm). The graphs show varying results, seeming to relate to the specific settings. As seen in figure 6.3, the sessions from 0-20 and 60-80 are with -20 dBm (3.5 meter radius), the 20-40 and 40-60 are with -16 dBm (7 meter radius). Expectedly the advertising interval clearly also had an effect. The best settings in the 5 meter tests were -20dBm+100ms (sessions 11-20) and -16dBm+100ms (sessions 21-30). In the 2.5 meter tests the setting -16dBm+100ms (sessions 51-60). -16dBm+100ms from sessions 51-60 proved to be the overall top performer when it came to hit rates, as is easily seen on the graph.



Graph 6.8: Graph that shows the hit rates for adjacent beacon's signal on the checkpoints

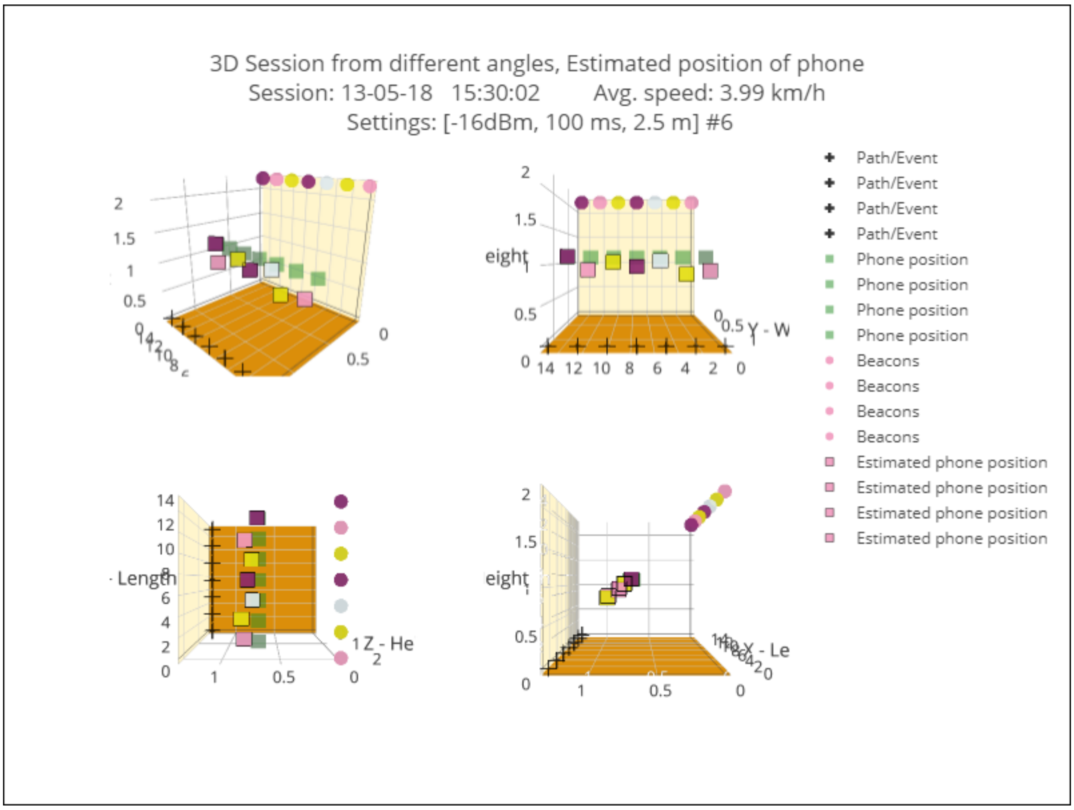
Graph 6.9 shows the average difference when only considering the closest beacon when at a checkpoint. The most accurate distance estimation for was with 100 ms advertising interval, with low difference for -20dBm+100ms (sessions 11-20) in the 5 meter tests and both -20dBm in the 2.5 meter tests (sessions 61-70 and 71-80).



Graph 6.9: Avg. difference in meters per session, considering checkpoints with offset +/-0

Graphs 6.10 and 6.11 visualizes "hits" in a 3D space representing the hallway. If a hit is present, the graph shows estimated position based on whether the distance estimation was too high, too low or just accurate. It places where it thinks the phone is on the X-axis, based on the estimated distance. This works because if the signal from the adjacent beacon is received on the checkpoint, then we can calculate the hypotenuse for the triangle. We know when a scan is at a checkpoint, that the beacon, checkpoint and phone line up on the X-axis. We also know the measurements and numbers for that moment in time as seen in figure 6.2. Thus, we can assume that we have a right-angled triangle with 90 degrees in the lower right corner, a 32 degree in the angle from the beacon to the phone and that the hypotenuse is whatever the AltBeacon SDK estimated based on the RSSI. With that information we can calculate the length of the sides of the triangle, and by that finding the missing YZ coordinates and position them in the 3D space. Details on the graphs are in the picture, but one is from the -16 dBm and 100 ms, the other from -20 dBm, 100 ms. The sessions were two of the highest scoring in terms of the previously mentioned "hit rate", thus showing two sessions where we were closest to the ideal situation.

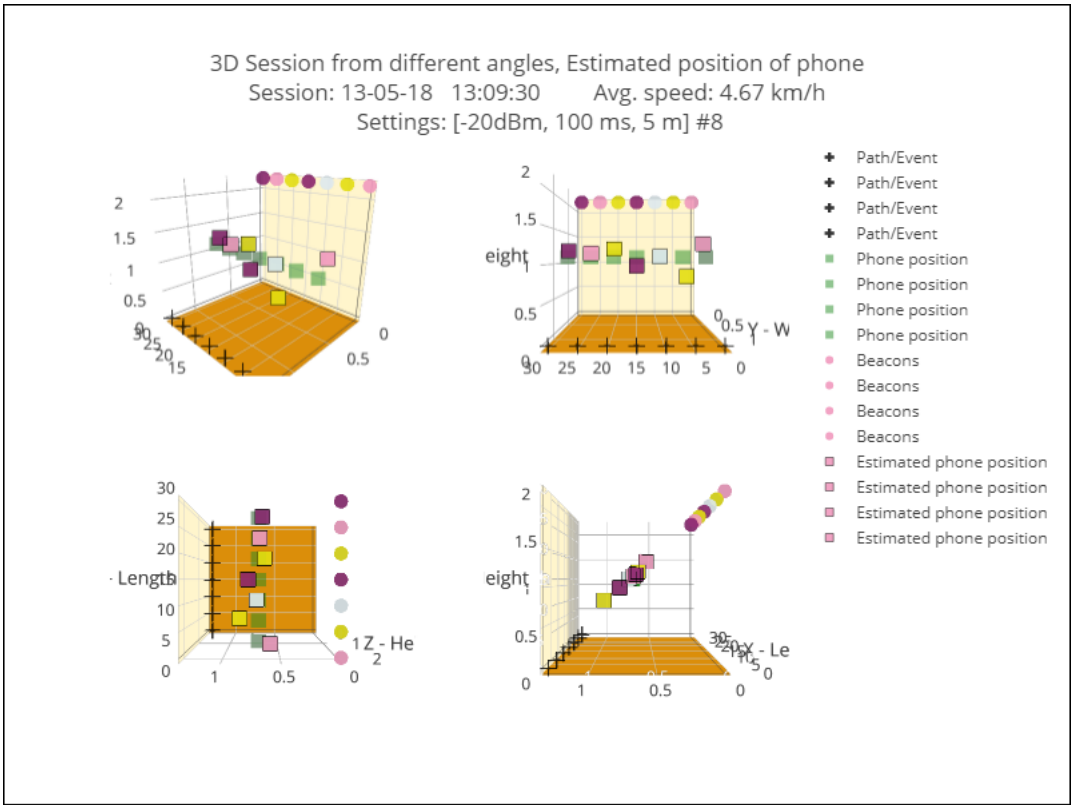
The 3D graphs only show the position estimation for the adjacent beacon to the checkpoint (+/-0 offset), which is what allows us to assume that the estimation leaves at the same 32 degree angle. Much more advanced and detailed graphs can be created, using



Graph 6.10: Estimated positions based on the checkpoints and their adjacent beacon

all the beacons at the checkpoints and scans between checkpoints. This would require further calculations, and one would also preferably filter the data to most accurately be able to visualize the estimations in the same 3D space. Towards the end of the project, there were not enough time for me to do so.

The 3D graphs generally seem to show that for short distances the estimates are somewhat accurate, and seemingly very suitable for proximity based applications. For precision positioning without additional means and filtering, the story is less promising. If one considers all the signals received from all the beacons at every scan, that is even more so the case.



Graph 6.11: Estimated positions based on the checkpoints and their adjacent beacon #2

Table 6.6 shows the values found, when looking at all the sessions. If one only considers the beacon associated with the current/last seen checkpoint, it averagely missed by 0.64 meters. 0.64 meters averagely missed when the beacon at the closest is 1.3 meters away, and at the furthest a bit more than 2.5 or 5.0 meters away, which isn't too bad. However, if we consider multiple beacons for all the scans the average goes up quite drastically.

For all the 80 sessions		
Offset	Only scans at checkpoints	All scans
+-0	0.624 m	0.624 m
+-1	1.242 m	4.012 m
+-2	1.827 m	5.677 m
+-3	2.151 m	6.195 m
+-4	2.224 m	6.290 m
+-5	2.229 m	6.317 m
+-6	2.241 m	6.320 m
Avg.	**1.791 m**	**5.06 m**

Table 6.6: Averagely how much the estimated distance missed by for all sessions

The four settings, average across all variances		
2.5 and 5m, (+/-0) to (+/-6), all scans and checkpoint only scans		
dBm	ms	Average difference
-20	950	1.61 m
-20	100	1.99 m
-16	950	1.92 m
-16	100	2.50 m

Table 6.7: The avg. difference for all the variances of the settings

Table 6.7 shows the values for each of the setting, when we take the averages from both the 5 and 2.5 meters, from +/-0 to +/-6, from all the scans and the checkpoint only scans. It was boiled down to have a final set of values that say: "these are the average differences", and the values are the results of getting the average of all the different perspectives. Interpreting and looking at all the possible perspectives and combinations would go beyond the scope of and purpose of this thesis. What the numbers tells us is that average difference is higher when the advertisement interval is lower, and the -20 dBm were more accurate than -16 dBm. However, for the 100 ms advertisements it is likely that there are more samples collected, similarly as -16 dBm has longer range than -20 dBm. More samples in one part compared to another skews the results, additionally the settings that have higher rates of samples are also likely more affected by signal reflections. The more frequent the signal advertisements, and the longer the signals travel, the more chances they will have to be affected by disturbances and fluctuations.

6.2.5 Conclusion

Approximately 0.5 meter error was found when only looking at the closest beacon, without other filters. Seemingly to get the most optimal results one should filter out the data, but as a means of assisting in answering RQ1 I argue that the data is sufficient to answer the question.

Steve Hegenderfer from the Blutooth SIG stated the following about a large retail store in which beacons were deployed: *"...equipped with Bluetooth beacons, about 200 of them. They'll provide indoor location with about 5-6 feet of accuracy, and they need that type of precision in this retail space where shoppers need to be located in the right aisle to find the right goods."* (Sterling and Hegenderfer, 2014). He is seemingly thinking in terms of a proximity based micro-location, which is supported by one the later statements he made: *"Beacons are all about proximity, they are not about absolute location."*. I would argue that for proximity and contextualization purposes like presenting a list of nearby products, and what Hegenderfer described, the results show that BLE beacons are indeed sufficient for micro-location.

Whether or not BLE beacons provide sufficient technological basis for micro-positioning, depends on what accuracy one needs. Micro-positioning has been explained as high accuracy positioning within bounds of centimeters, but apart from that there aren't any specific bounds defined. The accuracy number or bounds of which the accuracy must be within for a retail store for precision navigation is not known. For micro-positioning of the kind needed for blue-dot navigation and constant precision tracking within bounds of for instance 30 centimeters, BLE beacons are not the most optimal choice as the only technology used. It seems much more viable as part of a hybrid system, especially in regard to "traditional" deployments of the beacons (a couple here and there, in corners, pillars, etc.).

6.3 Performance testing with predecessor comparability

In the previous sections the performance testing has been presented, that performance testing builds onto what Saetre (2017); Godoy (2017) did but is not really translatable to the data they presented. To get some comparable data, as to be able to compare and say something about the relation between them and the data they produced, a portion smaller performance testing after their description is conducted.

6.3.1 Testing environment and parameters

From the previous section and testing, there are some differences in this testing that needs to be noted. Firstly, the beacons were on the floor, not on the wall. Secondly, the button events were not when at the point closest to the beacon, but rather when in the middle of two beacons (so the middle point between two button events in this testing is the same as an event in the previous sections). Thirdly, the markers used were also different, the markers they placed down in 2017 is still intact and were therefore re-used, figure 6.9 shows the approximate positions the beacons were placed at. This part of the performance testing was conducted 15 times, giving 15 graphs that can be used for evaluation. The Stass app with the same GUI was used for this testing, since the same kinds of data as collected previously is needed.

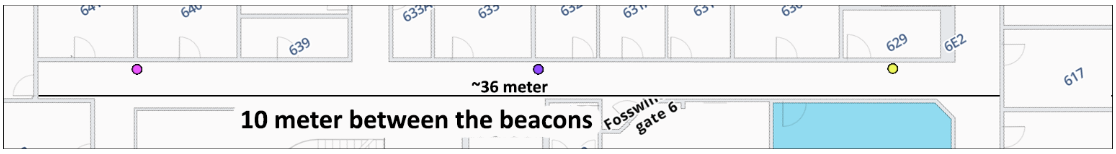


Figure 6.9: The approximate placements for the beacons in the 10 meter tests

In other words, this part of the performance testing that were done exactly like specified by Saetre (2017); Godoy (2017), the three location beacons without UWB were used, as it is the same type of beacons they used. They were set to a broadcasting strength of -16 dBm and an advertisement interval of 100ms, which were one of the test parameter cases they had. Therefore, this performance testing done for comparability is comparable to their *'122n'* tests, which indicate -16dBm, 100ms, near(10m) distance and normal walking speed. The testing parameters, the placement of the beacons, the path to walk and the markers where one would push the trigger is exactly the same. This performance testing was done to gather data that were directly comparable to the data they produced, as a means to evaluate and see if there is any improvements in the slightly newer technology. When they needed a way of evaluating their findings, their approach where to filter out some of the graphs and then apply these questions to each graph:

1. Does the resulting graph accurately represent how we moved through the regions during the test?

2. Is the graph smooth(not choppy) depending on the physical distance to each beacon?
3. Does each graph line peak approximately in the middle between each button entry and exit event?
4. Do the three region graph lines peak at approximately the same signal strength?
5. Does each ranging entry event have corresponding exit events and vice versa?
6. Do we have one monitoring entry and one monitoring exit event per region?
7. Do we have any monitoring exit event(s) for the last region (entered)?

Question 5, 6 and 7 relate to concepts that have already been established as not useful to include in subsection 6.3, thus they are disregarded for the performance testing. The predecessors stated in their theses that question 5 says more about their implementation and questions 6 and 7 were aimed at finding a bug in the Estimote SDK.

According to Saetre (2017); Godoy (2017) question 1 is meant to reflect whether or not the impression is that the graph indicates the movement during the testing accurately, question 2 is about seeing if the signal is picked up and indicates the approaching and moving past each beacon accurately. Question 3 asks if the beacon signal were strongest when walking by the beacon, which is in the middle of the two events. As the monitoring is disregarded it would be easier to create a button event when closest to the beacon, but for comparability of the graphs their methods were followed. Question 4 looks at consistency, seeing if the beacons' signal peaked equally, which one would expect as they have the same settings. The data generated by answering these four questions, are what they stated serves as the performance score, and they found that for their five selected 122n graphs the performance score were 33.3%. They calculated this in a spreadsheet representing no with 0, and yes with 1, with 1 then indicating that the graph presents what can be interpreted as good performance. The higher percentage the better the performance, one would expect the performance score of this performance testing to score higher than 33.3% (due to newer equipment).

They do also note that these questions generate subjective data, because the questions are guided by their assumptions and observations. They argue that the data is valid for the purpose of determining the usefulness of the technology for their use cases. As a means of the comparison, the questions 1-4 will be applied to the graphs created from the performance testing that were done for comparability. This will then create the same kinds of data about the graphs, for the four questions at least, which can then be used for comparison. Additionally, some more cold hard facts about the accuracies during the testing will be presented.

6.3.2 Results

For question 1 the deciding factor were whether or not it seemed to have picked up the signal somewhat consistently, creating "mountain" like graphs, as it indicated that there were an approach and exit to all the beacons. Saetre (2017); Godoy (2017) were aiming for a bell shape, the graphs produced in this testing show nothing similar to the bell curved shape. The answer to question 2 ended up always being 'choppy', likely due to the frequent scanning from the phone and the normal walking speed, therefore the answer was always no. Question 3 were based on the signal approximately peaking between the button events, in some of the cases it is a bit earlier than the exact middle-point. Question 4 was deemed as a yes, if the difference were not more than around 5 RSSI, which is the deviation that Saetre (2017); Godoy (2017) used.

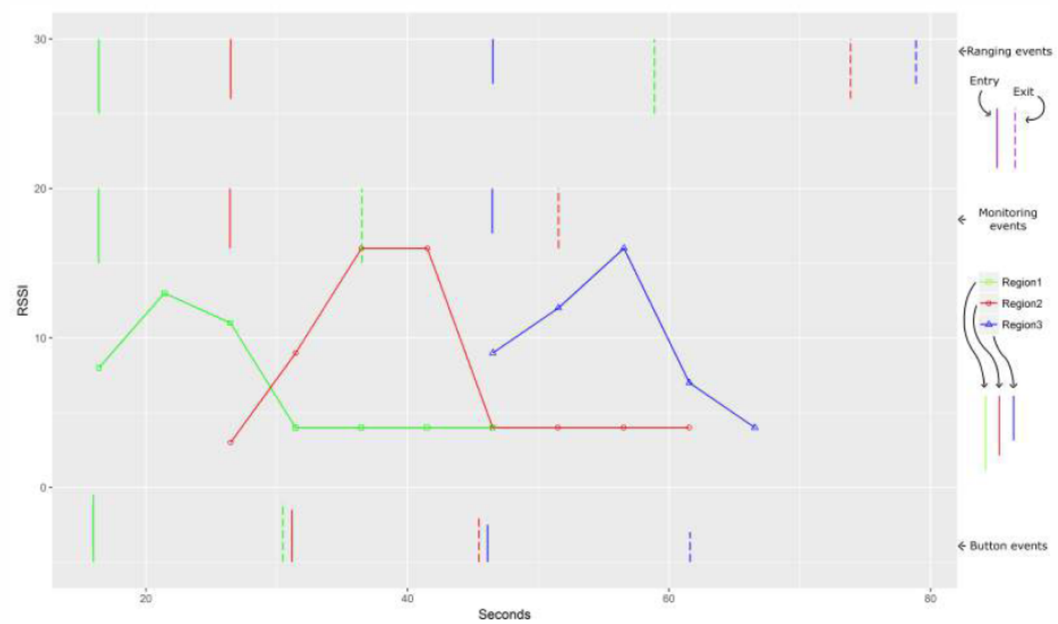
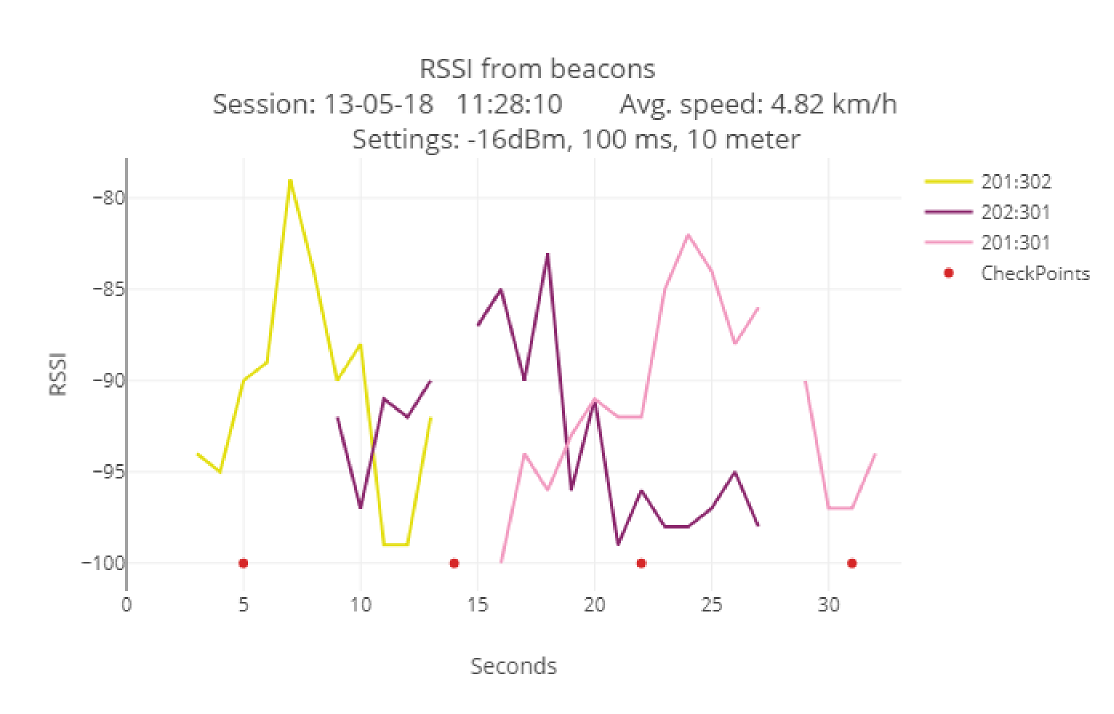


FIGURE 5.7: Test 122 graph example: -16 dBm, 100 ms, near

Graph 6.12: A graph from the comparable test done by the predecessors

Graph 6.13 shows the 8th graph from this testing, which is one of the three highest scoring graphs, which can be seen in figure 6.10. In the graph, there are only the three location beacons without UWB, the lines match the colors of the beacons and the "names" are the major and minor per beacon. In other words, the order of the beacons are as seen in figure 6.9, the path goes first past the yellow beacon, then purple and pink. One does see a resemblance and similarity in the graphs, even though there are some differences. All the predecessor comparable graphs can be seen in Appendix B, subsection 11.1.5.



Graph 6.13: One of the highest scoring graphs

The graph 6.12 shows what is known as 'figure 5.7' in the Beacon Performance Testing chapter in their theses (Saetre, 2017; Godoy, 2017). It shows that they used 80 seconds on walking 40 meters, which translates to a speed of 0.5 m/s or 1.8 km/h. The StepCalibration showed that I walked on average a bit faster, at 3.9 km/h. Rose and Gamble (2005) wrote that the average cadence for individuals in the age group 20-25 is 115 steps per minute. The StepCalibration showed that my average step length was 0.64 meter. To find the speed one take the distance and divides it on the time used to cover the distance, to find the distance we multiply the steps with the distance of each step. This gives us: $(steps * stepDistance)/minute = metersPerSecond$, to convert meters per second to kilometers per hour we multiply by 3.6. This leaves us with $((115 * 0.64)/60) * 3.6 = 4.416$, so by these data I would ideally walk with an average speed of 4.4 km/h. This is individual and based on multiple factors of course, however based on the data they presented in their graphs it seems their "normal" walking speed were very low compared to what one would expect. Which might indicate why their graphs are also "smoother" and mine "choppier". Another factor that plays a role is how often their phones were set to scan for BLE packets, which were not stated. During the tests in this project the phone scanned for BLE packets for 1000 ms, then has a pause of 0 ms, then it scans for 1000 ms and repeats this process until stopped.

	Question 1	Question 2	Question 3	Question 4	Sum
Graph 1 (111848)	0	0	0	1	1
Graph 2 (112011)	0	0	1	1	2
Graph 3 (112131)	0	0	1	1	2
Graph 4 (112246)	0	0	0	0	0
Graph 5 (112357)	1	0	1	1	3
Graph 6 (112539)	0	0	1	1	2
Graph 7 (112656)	0	0	1	1	2
Graph 8 (112810)	1	0	1	1	3
Graph 9 (112925)	0	0	1	0	1
Graph 10 (113041)	0	0	1	1	2
Graph 11 (113155)	1	0	1	1	3
Graph 12 (113308)	0	0	0	1	1
Graph 13 (113421)	0	0	1	0	1
Graph 14 (113540)	1	0	1	0	2
Graph 15 (113650)	0	0	0	0	0
	Total 0 (No's)		35		
	Total 1 (Yes's)		25		
	Percentage/performance score		**0,4166666667**		

Figure 6.10: Spreadsheet containing the values/answers for the questions on the graphs

6.3.3 Conclusion

Based on the subjective evaluation, which is based on the same methods used by the predecessors, the performance score ended on 41.6 %, which is higher than the 33% they found. The evaluation method is imperfect, but as a means to be able to directly compare this was the most straightforward approach. It does although indicate whether or not the results are within the expected bounds, and therefore have a certain value. Based on this it does seem as there are improvements in the technology, if one takes into consideration aspects like the walking speed differences.

In regard to RQ1, this shows that there are indeed improvements with each iteration of the BLE beacons, and it seems there are room for more. Based on the graphs and data from this part, it does not seem to be the case that the BLE beacons alone is sufficient for micro-positioning in a retail store. For micro-location however, the beacons still seem very sufficient.

6.4 UWB - Auto-mapping accuracy testing

This section discusses the UWB beacons, and their automapping functionality. It looks at how accurate it is and discusses briefly the results found.

6.4.1 Testing environment and parameters

As a simple way to validate the accuracy of Estimote's UWB automapping functionality for the beacons, some quick and simple tests were conducted. The automapping functionality were used through the iOS app Estimote Indoor, which can create floor plans automatically with the UWB beacons. The experiment consisted of placing the beacons, using the automapping functionality and physically measuring the distance between the beacons. The automapping functionality finds the distance between each beacon, and the point here is that it is supposed to have centimeter-level precision. Therefore, this was deemed the simplest form of validating the accuracy, which do have a vaguely indirect relevance to RQ1 as the UWB technology is in the BLE beacon. It is likely that devices with more than just one technology will be used in these kinds of systems, and the beacons are advertised as BLE beacons with UWB.

Figure 6.11 shows the test locationy, the beacons and their approximate placement have been drawn onto the places they were placed. The rooms 635 and 647, and a square of measures 1x1 meter and one with the measures 0.5x0.5 meter was used. The gray dots represent the white UWB beacon, as white color was close to invisible on the map. It is important to note that the measurements are not of the rooms, but the distances between the beacons. The following was the step-by-step actions taken:

1. Place beacons
2. Measure with UWB automapping
3. Measure with physical measuring band
4. Write down the measurements
5. Plot into spreadsheet and get differences
6. Get average difference for each room/square
7. Find average difference based on the average difference of all the rooms/squares

Figure 6.11: The approximate placement of beacons in the two rooms used UWB test

6.4.2 Results

To find the accuracy, the difference for each A-B (beacon to beacon) distance per room is found. There are four beacons, and as they are placed in square/rectangle shapes there are four distances measured for each room. As illustrated by figure 6.11, the beacons had the same beacon to beacon relative placement, the specific position on the image are approximate. So disregardless of what room or square were being measured, the white beacon would be measured to the yellow and purple beacon. This was done so that it would be easier to compare the data, as the beacons had a standardized setup. Table 6.8 contains all the data gathered by the UWB testing, and it is divided like this: Firstly, it is divided into rooms, and each room has four distances measured, white to yellow and purple, and pink to yellow and purple. Then the four measured distances are divided into: UWB, which is what the automapping measured. Physical, which is what the measuring-bands showed and the difference, which is the difference between the two. At the end there is a row, which contains the average error for each distance for each of the rooms/squares. Lastly those four values are summarized and divided by amount of different rooms/squares.

Since the automapping sometimes measured too little, and sometimes too much, the absolute values were needed once again. The goal was once again not to find out whether it generally missed by too much or too little, the goal was to find out how many centimeters/meters it missed by on average. Thus, both negative and positive numbers in the calculation would skew the result.

Physical and automatic measurements (in meters)								
Rooms	635		647		1x1 square		0.5x0.5 square	
	White	Pink	White	Pink	White	Pink	White	Pink
UWB								
Yellow	3.64	4.26	3.45	4.75	1.41	1.21	0.76	0.78
Purple	4.26	3.64	4.75	3.45	1.21	1.41	0.78	0.76
Physical								
Yellow	3.39	3.47	2.89	5.26	1.0	1.0	0.5	0.5
Purple	3.47	3.39	5.03	3.27	1.0	1.0	0.5	0.5
Difference								
Yellow	0.25	0.79	0.56	-0.51	0.41	0.21	0.26	0.28
Purple	0.79	0.25	-0.28	0.18	0.21	0.41	0.28	0.26
Average error per distance								
	0.52		0.3825		0.31		0.26	
Total average difference per measurement								
37 cm / 0.37 m								

Table 6.8: The measurements from the UWB testing

The final value being 37cm / 0.37 meter. 0.37 meter is averagely how wrong the UWB automapping were at estimating the distance between two beacons, in these four tests. This is less accurate than expected, but it is nowhere near inaccurate enough to be disregarded as technology. Based on the findings, I find that the technology shows promise, and it might be able to do the job for micro-positioning.

6.5 Discussion of the experiments

6.5.1 Beacon performance testing

The physical measurements may vary slightly due to human error, since I am doing the walking. I found that the phone while I were holding it were about 1.10 meter off the ground, while waking the phone might be five centimeter too low, and I might go 15 centimeter too much to the left. The speed also fluctuates, generally one can argue that these measurements are prone to some minor inconsistencies. The only way to avoid this, would be to for instance build a robot of some sorts that could follow exactly the same path and the same speed every time. However, doing this would be less realistic in the context. The objects moving in the system that is described in this thesis, will be held by humans. I argue that these inconsistencies aren't significant enough for it to be a problem, I do however acknowledge that they are there, and they have an effect on the end result.

A problem when evaluating whether or not the data produced is sufficient for micro-positioning, is that it depends on what accuracy is needed. In this thesis in the context of retail stores, and I have not found such a value.

A known problem with the signals from the BLE beacons (this is not only a problem for BLE beacons), is that the signals are affected by fluctuations, disturbances and obstacles. In a store, there would often be much more space and obstacles. The hallway isn't too large in size, making the signal reflect and bounce off of the surfaces more than it perhaps would in a store.

The distance estimation is just that, an estimation. The estimation provided by AltBeacon is considered the best option available and the "truth", but there are other ways of estimating the distance than AltBeacon's standard distance calculation which is used in this project. There might be alternative distance calculation approach better suited for stores, and for small hallway, but solutions for this "problem" have not been explored. In other words, the accuracy in the signals from the beacon might be better than the data shows. However, it might also be worse, it might also be just as accurate as seen in the data.

6.5.2 Beacon performance testing with predecessor comparability

The testing done was based on the work of Saetre (2017); Godoy (2017), their performance testing was evaluated by them evaluating the graphs they produced, as mentioned they acknowledge that there is subjectivity in the data generated by their evaluation. They argued that the data still were valid in terms of determining the usefulness of the technology. The graphs produced give some indication to the accuracy, and evaluating the graphs by answering questions about them do give a sort of summarizing indication of the perceived accuracy. Answering questions about the graphs are not my preferred approach to evaluating the data, but these comparability tests were done as it is interesting to see whether or not there are improvements in the current iteration of the technology. I do think the graph evaluation approach produces value, to some extent. Having the beacons on the floor during the testing is another not optimal aspect.

6.5.3 UWB testing

In the fall of 2017 when early development was being done, and familiarizing and experimenting with the beacons were on the agenda, the UWB automapping functionality were tested. It worked rather smoothly and there weren't many problems, apart from the blue-dot navigation Estimote's demo app provided being sluggish and not working as optimally as hoped. However, as of early May 2018 when the data about the automapping were collected things did not go as smoothly at all. There were various crashes, error messages and bugs that made the process quite the hassle. Which is why only four rooms/squares were mapped, regardless of hassle the mapping of the rooms did produce usable data. A larger sample size, with also larger rooms would be interesting to investigate. The version of the app used when conducting the UWB tests, were the newest at the time, version 2.4.6.

A user posted on Estimote's community sites asking about the repeatability and consistency of the automapping, while stating that he measured the same room three times, and got varying results (at best 0.3 meter, at worst 1.0 meter difference in his testing) (Estimote, 2017a). Which might speak towards non-optimal software from the Estimote Indoor app, as the UWB signal is supposed to be much more reliable than the BLE for measuring distances. Although the BLE+UWB beacons as a technology is still young, so expecting perfection right away might be a bit demanding. The impression is that there is plenty of room for improvements. Estimote states that the accuracy of the UWB functionality of the beacons can be expected to be around 25 centimeters (Estimote, 2018a), whilst other beacons like Decawave's DW1000 with UWB claims to provide accuracy around 10 centimeters (Zafari et al., 2016; Jiménez and Seco, 2016).

The sample size for these tests are quite small, so giving a definitive yes/no to whether the technology should be used is not possible. The results showed less accuracy than the 25 centimeters specified by Estimote. There might be several causes, the conditions might not be completely optimal, the software calculating the distances my not be optimal, it is hard to pinpoint exactly what causes the variances. When I stated that the technology shows promise, it was with all of this in mind.

6.5.4 The venue

As mentioned, the hallway is likely not the most suitable location for the testing. It also doesn't share too many similarities with a store. Skjetne (2016) cited Abowd and Mynatt (2000), stating that they (Abowd and Mynatt): *"...claim that ubiquitous systems need* *to be deployed in a realistic context to be tested properly.".* Some of the aspects that is mentioned in this discussion-section would benefit from testing at a more realistic venue and setting, and it would make the data better suited for addressing the research questions.

In this section certain aspects and problems in the experiments are discussed. The degrees of significance and effect it has on the end result are varying. However, it is important to acknowledge and be aware of some of the factors that ultimately have an effect on the result. If I were to address and pursue all these aspects, and find the best and most optimal solutions to them all, this thesis would never be finished.

6.6 Conclusion

In summary, based on the data produced and analyzed it appears that the updated technology has improved. The UWB technology shows promise, it seems to be a technology that will increasingly prove useful in IPSs. The BLE accuracy achieved in the tests weren't worthy of any celebratory cartwheels or creating additional hype. The purpose of this chapter was to get data to use to answer RQ1, which asks if BLE beacons provide sufficient technological basis for micro-location and micro-positioning in retail stores.

I argue that the findings show that no, BLE beacons do not provide sufficient technological basis for micro-positioning in retail stores. For micro-location however, it is indeed sufficient.

Although not suitable for blue-dot navigation alone, BLE might very well be used as a contributing technology together with some other technology in a hybrid system. Like the BLE beacons with UWB technology used in this thesis. Alone BLE has proven sufficient for proximity-based usages, like determining what products are nearby. It can be used to position a user to an area in the store, but micro-positioning and blue-dot navigation based on traditional BLE deployment in a retail store isn't sufficient.

ESLs with BLE could however be an approach that might work for proximity based blue-dot navigation, as there in most retail stores are so many products and prices that the coverage around the products and shelves would be very good.

7 Interview and survey

In this chapter, the interview and survey that were conducted will be covered. It consists of a semi-structured in-depth interview with an expert in the retail store domain, and a small survey consisting of 10 shorter sessions with an unstructured interview and questionnaire. The survey was conducted with Information Science master students, which can be seen as IT experts.

7.1 Interview

This section will cover the interview that was conducted and discuss details around the method of interviewing and the findings that were made.

7.1.1 Semi-structured interview

The interview can be categorized as semi-structured and followed many of the aspects that is described in the chapter on 'Interviewing in qualitative research' by Bryman (2016).

There were various guiding points, in terms of topics, themes and some guiding questions. In the list below are some of my own guiding points that were used in the interview. The ones in the list were amongst the most interesting to get answers about, in my opinion. I did not expect clearly defined answers for every question, I was more interested in discovering what a person from his generation with his experience think about the evolution that has happened and likely will rapidly continue to do so.

- What do the person think of the situation with physical versus online stores today?
- What are the person's predictions for the future of the store-domain (physical, digital)?
- Are there different kinds of store that is more/less affected by the competition from online stores?
- Are there any improvements or steps that the stores who are negatively affected by the presence of online stores can take?

As a helping hand I decided to print out images that could be used as aid if some of the concepts were hard to visualize for the interviewee. Bryman (2016) wrote: *"Images may help to ground the researcher's interview questions. The kinds of things in which social researchers are interested are often quite difficult for others to relate to. Using a photograph may help to provide both parties to the interview with a meaningful context for their discussion."*. The images presented wasn't photographs, but rather printed images illustrating various aspects of the artifact and some of the concepts like the Google's Indoor Map of Ikea Round Rock. Presenting images was used as a powerful means of presenting a concept simply and easily, without having to describe in detail, most people have heard the idiom *"a picture is worth a thousand words"*, which felt applicable in this case as well.

Oates (2006) urges that one transcribe the recordings, as it makes it easier to search and analyze the data in written form. However, in this project there were more of a semi-transcription. I listened to the recordings and extracted the points from the conversation, and then re-played the parts that were interesting. I present the findings that were of interest to the thesis. Since it was a loosely structured interview, there were of course derailments and irrelevant conversation. That was also the plan, as Bryman (2016) wrote; *"What is crucial is that the questioning allows interviewers to glean research participants' experience in the conduct of the interviews."*. To best understand what the person thinks, and to collect the most information, one needs to allow deviations and sidetracks, and use them in such a manner that it ends up being beneficial. Like exploring it to see what the person wants to convey or use it to redirect the conversation. Flexibility and a casual feel to the interview might make the interviewee more comfortable, feel less pressure and thus be more susceptible to talk freely.

7.1.2 The interviewee

The interviewee is a male in his early 50's, he has a long career behind him in the retail environment and sales industry. He has worked at and managed a photo-store, had multiple B2B (business to business) sales jobs and worked many years specifically with selling products to retail grocery stores. The sales job also included hands-on work with the products in the stores, like figuring out placements and re-stocking the shelves. The last years he has been working as a traveling sales representative, visiting a vast number of retail grocery stores in his district. His technical skills when it comes to tools like computers and smartphone can be described as average for his age group, and he is familiar with some of the new technologies implemented into the retail industry the last couple of years.

7.1.3 Goal of the interview

The purpose and goal of the interview was several:

- Get deeper insight into the retail setting
- Investigate and learn about the developments in the business the last decades
- Discover the interviewee's perspective on modern day technologies and privacy
- Finding the interviewee's thoughts on the continued development of the retail business

- Discovering what the interviewee think should be done and is necessary to do to strengthen physical stores position
- Finding new and additional problem areas

Generally, the interview were also about me getting deeper insight into the evolvements in the retail industry, from a knowledgeable and different perspective.

"Both semi-structured and unstructured interviews allow interviewees to 'speak their minds' and so are used where the primary purpose is 'discovery', rather than 'checking'. They are therefore used for in-depth investigations, especially those aimed exploring personal accounts and feelings.".

The quotes above and below are from the book 'Researching Information Systems and Computing' (Oates, 2006), and he makes a great point of how this method of semi-structured interviewing is well suited for discovery. Even though I had some assumptions beforehand, the main purpose was not about verifying them. And the purpose wasn't to get data to use for drawing conclusions based on generalizations either. It was about this specific person and his experience and what his thoughts, beliefs and opinions on an industry he had been a part of for a long time were.

"They are not useful, though, for situations where you want to draw research conclusions that are generalizations about the whole population...".

7.1.4 How the interview was conducted

As mentioned the interview was recorded and the interviewee was given the standard form 'Informed consent form interview and user-tests', the form can be seen in appendix A, section 10.1. After the consent form were out of they, the interview started with free and open conversation, I tried to let him speak freely and have him do most of the talking. The interview shared many similarities with a normal conversation, but was conducted in a more controlled and purposeful manner that naturally comes with the planning and the semi-structured form of the interview.

The recording had a duration of 49 minutes and 57 seconds, and it could be divided up into the parts: The first was about the interviewee and his background, the second was about the interviewees thoughts, opinions and predictions for the retail industry in light of technology, and the third was about some of the concept that systems like Stass could provide. The concepts and features in Stass were introduced at the end, to try to avoid unnecessary bias in the answers on what the interviewee thought about the future of the retail industry.

7.1.5 Summary of the interview

In the start of the interview the interviewee's career was explored, what has he been doing in his career, and what comments and thoughts do he have on the technological developments in the various niches that he has been working with. The interviewee has more or less worked his whole life with sales, either at a store selling products to people, or at a business selling products to other businesses. B2C and B2B sales and working as a traveling sales representative are some of the relevant types of jobs he has worked as. Most of the time it has although been in B2B in the grocery retail segment, selling various products for various companies over the years. He made a point of how they started with pen and paper to take orders from the stores, to using a laptop and a portable printer, to these days where they are simply using tablets and digital files. Further he made a point out of how the stores now have systems that keep track over stock, and orders necessary products based on what they have in stock and what they should have in stock. The systems know which shelves contains what products, so the pallets that come from the central warehouses are packed in such a manner that the employees of the store can spend less time moving the pallets around the store (since the pallet contains products close to each other). He sees his job (traveling sales representative for retail grocery stores) as a dying one, that is becoming obsolete due to technology.

At the time of the interview the interviewee's belief and opinion was that home delivery of groceries and ordering from online grocery stores are for the ones especially interested in technology, rather than the average Joe. He does although think that these kinds of services will take parts of the market, and become more normal. He believes the customers will have a better selection of products in physical grocery stores than online ones, even though the trend is opposite in other retail segments. Anyhow, he made a point of how consumption is increasing, and so is the population, and people won't stop needing groceries. Another argument he has for the physical stores are that humans are social beings, he is a strong believer in people and their need for human connections. He argues that chemistry and social skills can have impact on sales in stores, depending on the employees. The interviewee likes to get confirmation on his beliefs about a product before he buys it, especially if it is expensive, and he thinks others does too. Further he stated that there will always be an advantage to be able to try the bed, sit in the couch, inspect the quality and look of the fruits and vegetables, and see how crisp and vivid the colors of the television are.

When it comes to the data that is possible to collect, and what use cases there is for the data he is clear on the fact that this is nothing new. He has earlier been working on these sorts of problems, finding out whether the customer will pick the product from the bottom, middle or top of the shelves and so forth. The data collection on these kinds of aspects have been limited, and technology can improve data collection on such drastically. He argues that there are many things one potentially could do if one were able to profile the customers. He had a fresh example, two retail grocery stores from the same chain that was 300 meters apart from each other. The first of these two had more elderly customers and had only 1/3 of the annual revenue the second store did. The second store had mostly younger customers, and sold much more products, and there were some different product groups for each of the stores. On a general basis he thought there were quite different shopping patterns within these stores, and it is an example of how one can adapt the stores to the customers. An example of his was that the store which had the young people would want to be fully stocked on pregnancy tests, while the store with the older customers might not need the same quantity.

Other things he could imagine using the data for, that could be useful is finding where the traffic is in the store, where do people move, where is the best place to expose products. Finding where people moved could be done with asset tracking, having sensors on the shopping carts and shopping baskets are an approach, collecting data from people's phones are another. This kind of data collection brought up the theme of privacy, and the interviewee seemed opinionated that anonymization was important, and it was important to be careful when it comes to dealing with privacy. In addition to anonymization, the fact that the customers gets something back was important and that they would have the ability to opt-out. This clearly seems like a way to go but will come with drawbacks in terms of biased and skewed data, however that is a problem one need to deal with either way. As some groups might be more and less prone to opt-out, one need to find ways to compensate for these things. There are without doubt lots of research on the problem, in this age where recommendation algorithms are at every turn. There is a delicate balance here, in collecting data and respecting privacy, and making people comfortable with the whole process. The interviewee believes that if people start to feel like they are under surveillance all the time, there will be negative consequences, like people going other places where they feel less surveilled.

When going into some more specific concepts that are in the Stass domain, like Amazon Go and stores with few employees, the interviewee thought it were fascinating. He did although wonder about what if he couldn't find a product in the store? In that case the employees could help, but for instance systems like Stass could also be a great helper in locating these products. When I asked the interviewee what he would do if he went to a place and couldn't find the product himself, and did not get help to do so either, he responded: *"Then I'll get annoyed, and likely go elsewhere the next time."*. Then the interviewee was presented with the images showing the Google Indoor Maps at Ikea Round Rock and was explained how it for instance could be the foundation to a service he in the future might use to find these products. The interviewee liked the idea, especially for places like Ikea, which are quite large, but he commented that precision and accuracy were extremely important. He thought that navigation to specific products were too much work, and therefore thought that product groups and shelves seemed like better options. He was also skeptical with regard to the grocery store setting, as he argued that things move around too frequently, and no two stores were exactly the same. He explained that he visits multiple stores each day and he goes through a cycle, so he comes back to the same stores and sometime he gets very confused as things has changed from the last cycle.

When it comes to finding information on products, his method is to approach the employees of the store and ask them. He is not one of those who picks up his phone and checks the stores website, the manufacturers website or searches for the information online. Because even though the information is available out there, he must look for it. If and when he finds it, he argues that it is not given that he actually understands the information. He went on by saying that if he had the option to do something like scan a QR code, with his phone and then get information which he could understand, that was a service he would use. The interviewee then reflected for a few seconds, and then commented that these days getting help from the employees might not always be as helpful as one wishes either. As there are many young people working, for instance students, who might have limited knowledge of the products and it is often limited how much they work. They are although cheap to hire, which is important for the retail stores which are fighting to have the lowest prices. Having easily accessible information, with various degrees of information (layman to expert) will also help the employees become more knowledgeable and be able to better help the customers.

Targeted advertisement was something the interviewee had mixed feelings about, as he claimed he knew it worked. He had himself been a "victim" of targeted advertisement and bought something as a result. Additionally, he has been on the other side, where the company he worked for partnered up with someone and they sent targeted advertisement for gummy bears with vitamins to people who bought movie tickets for children's movies. An aspect that annoyed him was getting advertisement for products that he had already bought, for instance a vacation package, he thought it would be better to get for instance advertisement for related things to what he had already bought. For a vacation, an example might be advertisement for things to do in the area of destination for the vacation.

Then, I tried to see if he knew about any other problems that the retail industry was facing, something that technology perhaps could be of assistance for. The interviewee brought up theft and wastage. He pointed out that it was a significant problem which most stores face, and these days it has some extra consequences. Firstly, the store has a direct loss in money from the product not being sold. Secondly, if the product was stolen or the employee forgets to update the stock, the data system will still think that the product is a part of the stock. This in turn has the effect that when the systems do the ordering of products automatically, it will order the wrong amount. The result can for instance be that the store has less stock than what intended, and in the worst-case scenario the customers might face empty shelves of the product he is looking for.

Later when discussing the queues, self-checkouts and Amazon Go he mentioned that time-theft was also a problem. Both for the customers, store and employees. He proceeded with making the point that "back in the day" the stores usually had milk and bread as far into the store as possible, as most people needed and wanted those products, which in turned forced them to go through the whole store and spend more time. The longer the customer is in the store, the greater the chances are of them picking up additional products he stated. He then argued that he thought people didn't have a problem with spending time in the stores, it is about the unnecessary time wasted and the experience. For instance, standing in line for the checkout for five minutes he thought most people would be annoyed by, but five minutes extra walking around in the store would often be fine. So the point is reducing the wasted-time, or time that the customer feels are being wasted. At that point I introduced him to the last concept from Stass, the CloudQueue. Which was a feature he really seemed to like. As many of his thoughts and opinions about shopping and physical stores, and the reasons why he likes physical stores were benefited by it. Right before the end he mentioned that it is important that the customer feels seen, and he acknowledged that in larger stores feeling and being seen could be a problem, and he saw that the CloudQueue concept could serve as a substitute since the customer knows that help is coming.

7.1.6 Conclusion

The interview was in my opinion considered successful, in that it achieved what I had hoped. Inspiration, new perspective and new information for me. To try to summarize the biggest and most important points that were made, here are some take-back points:

- Time is an important aspect; the most important thing is to avoid "waiting" and what the customer experiences as unnecessary and wasteful use of his time. Apart from that the customers might be willing to spend more time if they feel it is worthwhile, so there lies a balance and trade-off in the stores vs customers time
- People are social beings, and some might be drawn to physical stores just for the social interaction
- Seeing the quality of the fruits and colors of the TV, sitting in the couch, lying in the bed you are considering buying is hard to do without physical presence of the products
- It is important people feel seen, in terms of that their presence is acknowledged and they can get assistance if necessary. At the same time, it is important that people don't feel constantly under surveillance as an individual
- Products and product groups can be used as navigational destinations, and apparently some of the automatic ordering systems already have some sort of positional information about products
- It is very important that systems like Stass are flexible and easy to make changes to, as stores tend to move things around
- Providing easy to find information, with various details of information is beneficial and if done right should be able to improve the layman and customers knowledge, but also the experts and employees

Apart from that my observation were that the interviewee saw the potential in the what one can do with the technology, but he clearly also saw the problems in privacy. He was also firm in his belief that people like physical interaction, they like social stimuli and meeting other people, and they like to be able to use their senses to evaluate a product, especially for things like beds, couches and such.

In regard to RQ2, the interviewee seemed to think that an app like Stass could be helpful for the customers, and that he believes some customers would use it for at least some of the features. Generally, he seemed positive, but he was obviously a bit concerned about privacy and would likely be a bit hesitant to Stass himself. For RQ3 there results consisted mainly of more ideas and new knowledge, which could prove useful when further developing the concepts and features of Stass.

7.2 Survey

In this section the survey that was conducted is described and presented, both the conduction of the survey and the results that were found is covered. Oates (2006) state that the point of a survey is to gather the same kind of data from a large group of people, in a standardized and systematic way. One then looks for patterns one can generalize to a larger population, the sample size should be at least 30 if one wants to generalize the findings of the sample to the whole population (Oates, 2006). He continues by mentioning that often surveys use questionnaires, but interviews and observations are example of other methods one also can use. The reason this is labeled as a survey is that it consists of both interviews and a questionnaire, and do attempt to get standardized data from the participants. The sample size is not big enough to generalize to the whole population. As master students in Information Science can be seen as experts in the IT domain, the survey was done with 10 experts in a relevant field. Therefore, it is considered data that is usable to indicate and be able to say something in terms of the research questions.

7.2.1 How the survey was conducted

The survey consisted of firstly letting the participants play around with / "test" the app, and then presenting and going through the app and concepts that follow Stass-like systems. After the "testing" and presentation of the concepts was done, they were asked to answer some quick and simple questionnaires, which would provide me with some data that I could analyze. Additionally, notes were taken during the survey if interesting or new perspectives, ideas or criticisms appeared. It was a sort of mash-up between user testing, with a simultaneous unstructured interview and a questionnaire at the end. The survey tried to find answers to and explore whether the participants thinks these concepts and features are worthwhile and useful. It was a short-term study, lasting for the duration of the time it takes going through the process for all the participants.

It took approximately 15-20 minutes for each participant, the survey had two main data generation method, the unstructured interview and the questionnaire.

Oates (2006) wrote about unstructured interviews: *"...the researcher has less control. You start things off by introducing a topic and then let the interviewees develop their ideas, talking freely about events, behavior or beliefs, while you try not to interrupt and are as unintrusive as possible."*. The explanation fit well with the interview, the participants were first introduced to the concept and the topics, at the same time the conversation went on while the subject used the Stass app. I did of course try to get the most information out of the participant and tried to be as unintrusive as possible to the participant's reasoning and speech.

The questionnaire was made after reading the guidelines provided by Bryman (2016); Oates (2006); Peterson (2000). Principles like BRUSO (Brief, Relevant, Unambiguous, Specific, Objective) that serves as easily applicable criteria to make sure the questions are good were used when writing the questions (Peterson, 2000). As well as attempting to have content validity and following question formatting proposed by Oates (2006) and Bryman (2016), like using a Likert-scale.

7.2.2 Goal of the survey

The user testing aspect wasn't recorded or paid attention to, it wasn't in focus, as the goal was not to find out whether or not the app was usable and had good interaction design. The app was merely a tool to aid in the presentation of the concepts, as a proof of concept app. What I wished to find out was what the participants thought about the concept, and what their takes on things like features and privacy were. Chapter 7 covered the more in-depth interview, the interviewee was a middle aged man with average technological skills but vast experience in the retail domain. In the survey the subjects consisted of fellow students at the institute, which consisted of people with above average technical skills, but with varying degree of knowledge and experience from the retail domain. The approach produced good insight, qualitative data and quantitative data.

7.2.3 Unstructured interview

The interview part of the survey is labeled as an unstructured interview, but there wasn't a rigid execution. It was conducted as a casual conversation that revolved around the relevant topics, with aspects from the unstructured interview. If especially new and interesting topics arose, I tried to dig deeper and get more information from the participant, as it could be valuable insight. The most noticeable and interesting points that came from this is discussed in the remainder of this subsection.

One of the participants had a lot of input, which came out during the interview part before the questionnaire. He seemed excited about the idea of easily finding product information, he stated that often on products there are buzzwords, like on the box of a computer it might say that it has 4 gigabytes of RAM, but not which kind of RAM. He also mentioned that he liked the free-roaming of the CloudQueue but that he had one thought, which I found interesting. The input was that in retail stores there are often various different section, in an electronics store there might be a section for TV's, one for computers and one for appliances. Every store employee might not know everything about every product, which is in agreement of the expert's belief in subsection 7.1.5. Therefore, he thought that one should perhaps be able to select what kinds of products one need assistance with. As to avoid an employee coming to assist the customer when it is his turns turn, only to find out that the employee is unable to assist due to lack of knowledge. One could perhaps consider where in the store the customer is located, and accordingly find staff for the section. However, when waiting in the CloudQueue, the concept of CloudQueue enables and promotes the customers to roam. Which potentially in some scenarios could make it difficult to determine what products the customer needs help with, based on the customers location in the store.

Another participant was worried about the accuracy of the CloudQueue, and gave the example: What if the employee are approaching the customer who's turn it is to be assisted, and the employee is guided to an area where there are many customers, how is he to know which customer? Which is a good point, the idea is although that one will have accurate micro-positioning, so that it shouldn't be too much of a problem. Additionally, one could have for instance the customers phone starting to vibrate when the employee is 10 meter away or something similar. The point is viable and certainly something one should address in the app, as functionality that should be included, but the problem is not considered a showstopper at all.

All the niches and special kind of stores people visit once or twice a year, which has their own apps, annoyed one of the participants. He stated that it felt wasteful to download their app to get 10% off something, and then just having it there dusting for a year, having it send advertisement wasn't viewed any better. This participant lead us into the subject of whether to have one app for every store, or one app for each store, which was originally a question I intended to investigate in the questionnaire. It was though found as a further work issue, rather than an issue that is heavily addressed in this thesis, and therefore not included in the final questionnaire. One could argue that whether or not people would use apps like Stass, might be affected by these kinds of aspects as well.

7.2.4 Questionnaire

The questionnaire was divided into three parts, one where the questions were yes/no or on a scale which would be the quantitative part. Another part where they were asked to give a bit more information on some subjects, which is considered the qualitative part. And a part were formalities like personals, consent to use their response and some initial insight questions were made. The general purpose of the questionnaire was to get quantifiable data on some relevant topics and with relevance to the research questions. The hope was that the qualitative data would either confirm or deny my initial beliefs and suspicions or add new information and perspectives that had not crossed my mind. Either way the questions all has value, although to what degree might vary. The questionnaire gives data-points that can be used to evaluate RQ2, and some of the questions are also relevant to RQ3. Some of the question also lay grounds for the research problem, showing that it is indeed important to investigate the topics of this thesis.

The questions in the first part were as follows:

1. I consent that this contribution can be anonymized and uses in the thesis, and I was given the consent form.
2. What's your age?
3. What's your gender?
4. Approximately how many times per week do you visit a physical store?
5. Do you use any apps related to stores today?

The questions in the first part were just to have gender, age and agreed consent to use their response. The purpose of question 4 were to get an initial feel over how often the participant found themselves in stores on a weekly basis, question 5 were to see if they had any experience in dealing with apps targeted at the retail domain. It also might give some indicator to whether or not the participant is skeptical about new technology, and if they might be so called early adopters who are excited about new technology.

The questions in the second part were as follows:

6. How likely is it that you would give up private information to get some benefits like the ones from Stass in return?
7. How concerned are you with who has access to data about you?
8. How likely is it that you would use an app like Stass?
9. How helpful do you think systems like Stass would be to its users?
10. Have you in the past couple of years left a store without buying a product because you didn't find it?
11. Do you think Stass and systems like it in some cases could be a sufficient alternative to getting assistance from a store employee?

Question 6 is very relevant, and the purpose were to give a general indication of to what degree the participants were prone to the trade-off in privacy/benefits that is often seen today. Question 7 is to get a feel over how concerned they are in general with who has access to their data about them, as that would affect whether they would consider using an app such as Stass. Question 8 serves as the best indicator to whether the customers would use an app like Stass, which is a part of RQ2. Question 9 directly asks the participants about to what degree they think the concepts and the app presented to them could be helpful for customers of retail stores, which also gives an indication to the first part of RQ2. Question 10 seeks to explore whether any of the participants how taken the step of leaving a store without the product they came for, which is interesting to see in light of the product finding functionality and the general purpose of Stass. Question 11 asks if the participant thinks that Stass could in some cases be an alternative to getting help from a store employee and is relevant to the self-assisting aspects of Stass.

The questions in the last part were as follows:

12. Are there any kinds of products you wouldn't buy online? If yes, what kinds of products?
13. Is there any other problems you think an application like Stass could solve? If yes, what?
14. What would it take for you to allow data to be collected from your phone?
15. If any, which of the features or concepts presented in Stass do you find especially promising?
16. If any, which of the features or concepts presented in Stass do you find especially problematic?
17. (Optional) Other thoughts on the project?
18. (Optional) Any comments on the questionnaire?

Question 12 seeks to investigate what kind of products the participants would prefer to buy from a physical store, speaking towards what kind of stores might be less affected by the presence of online stores. Question 13 seeks to find out whether the participants believe there are other purposes Stass could serve, and other problems it could solve. Question 14 were an open question, which purpose was to see what each individual participant would require in order to allow data from their phone to be collected. Question 15 and 16 were targeted at Stass, was there some of the features or concepts they particularly got excited about or found troubling? The questions 17 and 18 was optional, which asked if they had any thoughts on the project and questionnaire in case they had some good comments they didn't feel appropriate to write elsewhere in the questionnaire. These questions allowed longer answers, as opposed to the questions in part two.

The results of the questionnaire can be found in the Appendix A section 10.3.

7.2.5 Results from the personals and non-RQ specific questions

All of the participants consented to the use of their submissions in the thesis, the age varied from 23-27, there were 10 participants, of which 8 were male. The majority of males comes due to the fact that the majority of the master students in Information Science are male, so no representativity based on genders are claimed. Half of the participants uses some apps related to stores and retail today. The answers to question 4 varies greatly, as can be seen in figure 7.1 which shows their estimations of how many times per week they averagely visit physical stores. It seems the participants vary from planning all their purchases to going to the store once a day, sometimes more.

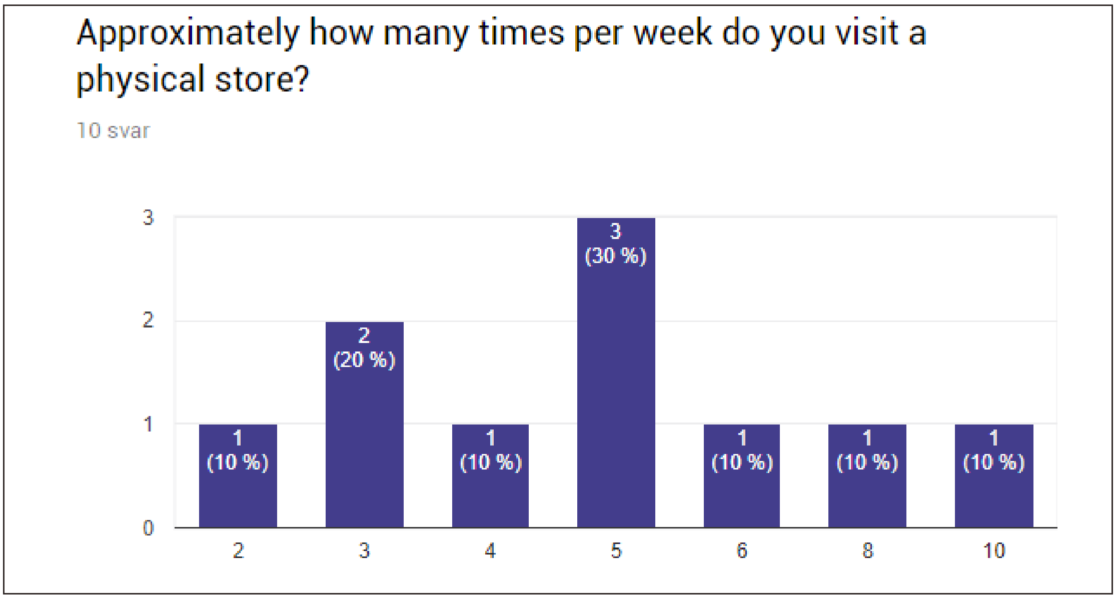


Figure 7.1: The results for question 4 in the questionnaire

7.2.6 Results from the quantitative questions

The questions in this part is targeted at RQ2, but in different perspectives. Questions 6 and 7 looks at the secondary part of RQ2, about whether the customers would use apps like Stass. Questions 6 and 7 looks at it indirectly by looking at what their standings on privacy issues are. The privacy aspect of systems like Stass is essential to get right, it may well be a deciding factor between failure and success if such a system were to be developed for the industry. Questions 8 and 9 are rather straightforward, question 8 says something directly about the secondary part on whether or not the customers would use an app like Stass. While question 9 asks what the participants think, do they see the artifact as helpful for its intended users, which is directly applicable to the first part of RQ2. Question 10 and 11 also generally is targeted at RQ2.

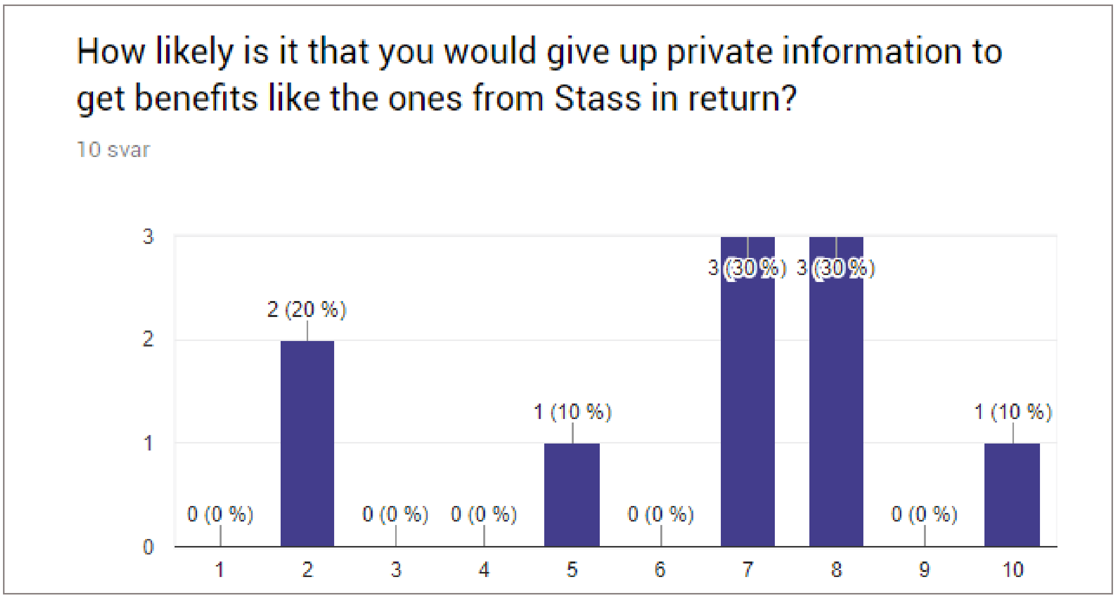


Figure 7.2: The results for question 6 in the questionnaire

The results of question 6 is seen in figure 7.2, and it depicts a group that would consider sharing private information if they get something they feel is worth it in return. Two of the participants would very unlikely shared private information to get benefits like what Stass could offer, one is neutral and the remaining seven is generally willing or very likely to do such a trade-off. This is promising in terms of indicating whether or not the customer would use such an application. Interestingly, while only two-three can be said to probably not be willing to do the trade-off, six are concerned with who has access to data about them. This might show that people are willing to do the trade-off, but maybe even more so if it becomes clearer what and how the data are treated. If that is so, one could argue that the GDPR really is something that will benefit both the users and companies.

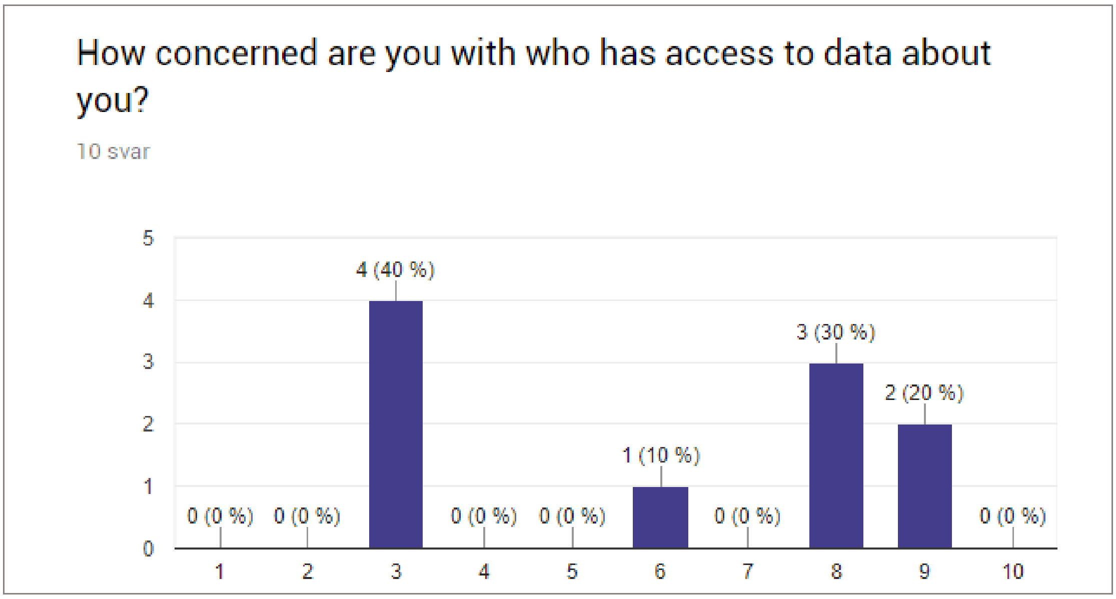


Figure 7.3: The results for question 7 in the questionnaire

The answers to question 7, as seen in figure 7.3 gives an interesting result, showing a split in the group. The scale from 1 (Not really concerned) to 10 (Very concerned) shows that four isn't particularly that concerned, while half of the participants are quite concerned, and one person is a little concerned. The average ends at 6.4, which indicates that there are concerns. The interesting part is although how one half doesn't really seem that bothered, while the other seem quite bothered, why such a split in a group of people who have much in common?

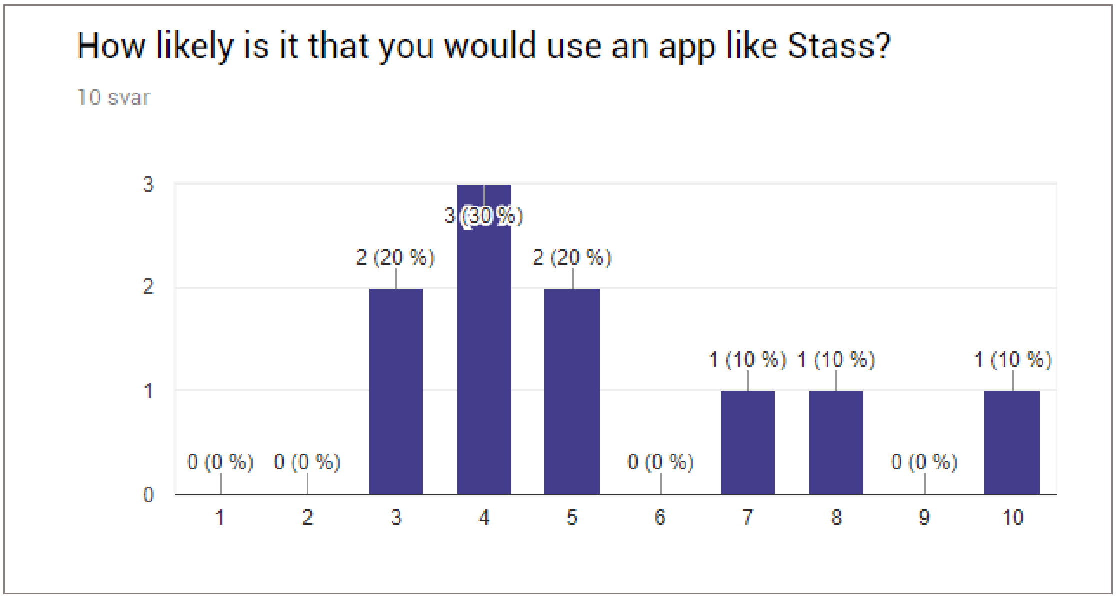


Figure 7.4: The results for question 8 in the questionnaire

Question 8 shows spread answers, when asking the participants how likely it is that they would use an app like Stass. Figure 7.4 shows the results, on the scale from 1 (Very Unlikely) to 10 (Very Likely), no one stated that it was very unlikely that they would use an app like Stass. However the majority (seven participants) were in the range of 3-5, which indicates that there is a problem here. It might be privacy concerns, they might think the question was targeted at the Stass app specifically (it was although made clear that it is about the concept, not the specific app). It could be that they might not think they need the assistance or maybe the concept isn't well enough understood by the participants or the concept not far/well enough developed. The minority (three participants) do however seem to believe they would use such an app. The answers for question 8 did give a rather neutral indication to RQ2, with the average being at 5.3.

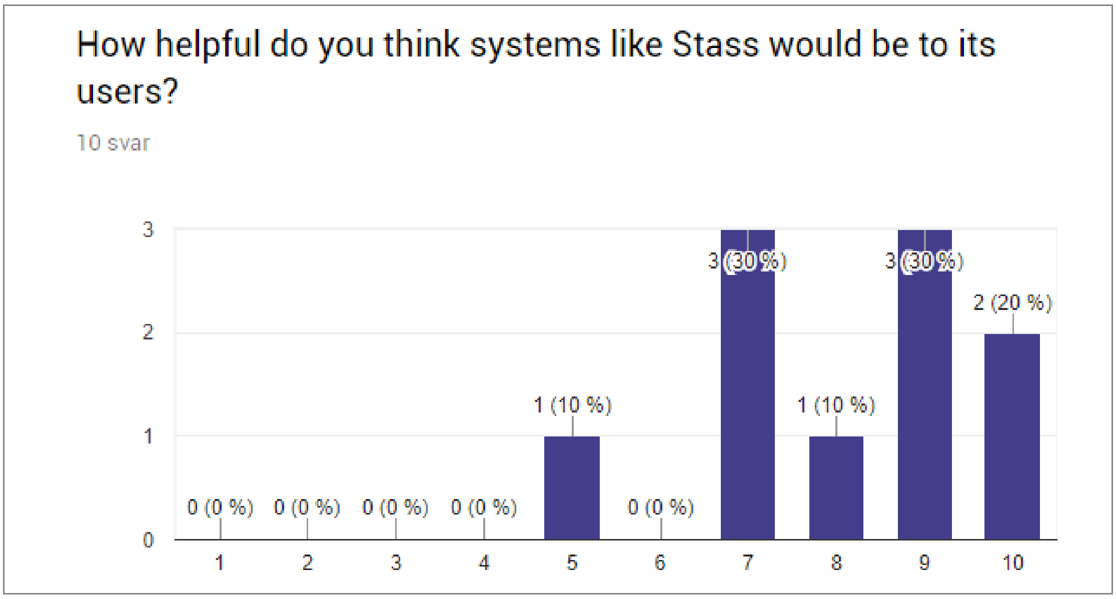


Figure 7.5: The results for question 9 in the questionnaire

Question 9 asks the participants directly, whether they think Stass and systems like it would be helpful to its users. Figure 7.5 shows the results, which can be said to be positive, the scale was from 1 (Not really helpful) to 10 (Very helpful), one person answered 5 which can be interpreted as the person at least deeming it a little helpful. The remaining nine participants answered 7 or above, in total the conclusion seems that the participants thinks Stass could be highly to very helpful.

Question 10 showed that seven of the participants has left a store within the past couple of years, without buying a product because they did not find it. While one person has not, and two persons were not sure. This indicates that systems like Stass, have a potential for being able to helpful for the customers of stores. Positive results in terms of RQ2, both for the first part about the helpfulness and the second part of whether the customers would use such an app or not.

For question 11, which were *"Do you think Stass and systems like it in some cases could be a sufficient alternative to getting assistance from a store employee"*, all of the participants answered yes. Which seems like an indication that some of the assistance people need help with in a store can be seen as trivial, and that Stass in terms of RQ2 would be helpful for the retail store customers.

7.2.7 Results from the qualitative questions

Most of the questions in this part is relevant for RQ2, trying to answer what the participants thinks are good and bad ideas, if there are other things Stass could help the users with, and discovering what it would take for them to allow data collection.

Question 12 seeks to find out if there are any specific types of products, that helps certain stores stay relevant and be less affected by the online competitors. Two persons responded no, that there were no products they wouldn't buy online. Furniture and groceries (especially fresh produce) were two types of products that were the most frequently answered, additionally came pharmaceuticals, instruments and shoes. There are certainly things that people prefer to buy in physical store, or at least be able to have physical interaction with on forehand. Some might visit the store to check a product out, and then decide later and perhaps buying through the online store, which is something the stores could use in their advertisement and marketing strategies.

Question 13 is very interesting in regard to RQ3, as it asks the participants specifically if there are other problems Stass could address, other features and functionality it should offer. Most of the participants had input, that also gives indication for RQ2 that there are additional things Stass could do to be helpful for its user and those features would also promote the use of the app. The question was: *"Is there any other problems you think an application like Stass could solve? If yes, what?"*. Four people answered no, it might be that they feel the app and what it does is sufficient, or they didn't have any apparent problems they felt Stass would be applicable to, or they just couldn't think of it at the time. Two persons stated that they would like for it to able to navigate between stores in a shopping mall, which is what many of the existing IPSs focus on. It would be a natural addition to such a system, and an incentive for stores to join Stass-like systems. One person said they would use it if multiple stores supported Stass, likely making the point that they prefer not to download an app for every store in the shopping mall or something similar to that. One person said that a customer shopping in a retail chain's online store, could be notified if someone were looking at the product in a physical store. Although doable, the value in the feature isn't mentioned nor does it seem that obvious. It does confirm for the online customer that other people also consider the product. It might be similar to what one often sees on traveling and trip booking sites, where it might say "X amount of people are looking at this trip/hotel right now". It does suggest that it is popular, other people consider it and it might pressure people into thinking "I have to act now, before it is too late". Other suggestions were being able to filter out products based on allergies, and perhaps filtering based on trends and necessities that people often have or follow. Like allergies, life-style choices and diets. The last input regarded prices, and including price comparison features and helping the customers find the best prices. Which is certainly an incentive for the customers, and there are services providing this already, absolutely something to consider as a part of such a system as Stass.

Question 14, asks an interesting questions, it asks what the participants thinks it would take for them to allow data to be collected from their phones. A couple got confused by the question, in which the clarification given was that: If you had to allow data collection from your phone to happen, what would your demands/requirements be? Two mentioned anonymization of the data, of which one also stated that he would not allow sharing or resale of the data. One person didn't have an answer, or didn't know what it would take. Three persons wouldn't require much, one of them stated that if they got something useful in return it was alright. One of them wanted benefits and it being clear what the data is used for, and the third of them stated that so many other services collects the data already that it wasn't a big deal to them. Another person wanted transparent use and secure storage of the data. The last person seemed more strongly opinionated than the others, the person stated that it depended on what the data would be used for, but generally he had several points he thought were important. The data needed to be collected in a clear and understandable manner, the user should be told what data is collected and what it is used for, and the collection should only happen when the app is used. It seems generally that anonymization, benefits, secure storage, transparency and clear use are concepts that are important to the participants.

Question 15 looked at whether the participants thought any of the concepts and features they were presented with appealed as promising to them. Two found the CloudQueue very promising, the other eight all mentioned the product finding and navigation as their top feature. Additionally, one of these persons liked the idea that if one searches for a product, and the stores doesn't have such products, options that are nearby are presented if they exist. All the participants thought that at least some of the features and concepts were promising, which support the concept of systems like Stass being helpful and the customers likely wanting to use such systems.

Question 16 investigated if the participants found any parts of the concept presented problematic, as a direct opposite of question 15, and four participants didn't feel that any of it were problematic. Two persons were concerned about privacy and data collection, one stating it needs careful consideration and one referring to 'mining customer movement patterns', which is assumed as the person pointing out the privacy issue that lies in that domain. The remaining three had skeptical inputs towards the CloudQueue concept. The first person pointing out that if it takes long one might find the product while walking around, which is a point, but CloudQueue is imagined not to assign employees to help customers find products, that is why the product navigation is such a big part of the concept. The point being that the most trivial helping situations, like finding a product or hard-data and information about the product, are addressed by other concepts in and parts of Stass. A second person mentions the part about the employee not being able to find the customer he/she is supposed to help when it is that customers turn. This comment came from the same person and was the same point that was addressed in subsection 7.2.3, which came out during the unstructured interview part. The third person of those three addressed that the location was not dynamically updated, and that customers might move while waiting in the CloudQueue. It seems that the person has misunderstood and addresses not the concept but rather the functionality implemented. As the dynamic updating of the customers position in the store and in the queue is of course the intention of the feature. The last comment addressed the battery life of the phones, which is actually a very important point, as having the Bluetooth chip always scanning does help drain the battery. With time the hope is that the battery-technology improves, and perhaps the battery usage of the scanning also decreases. It is likely that the users wouldn't use an app like Stass, if it drained their battery significantly, so that is certainly an obstacle one would need to overcome.

The questions 17 and 18 were optional, 17 asked for thoughts on the project and 18 the questionnaire. The answers were generally positive. Two thought the project were 'cool', one of them also liked the user interface and would like to see further work on the project. Another stated that he believes that when the technology matures more in the not too distant future there will be systems like this, which might indicate that the person believes the answer to RQ1 would be no, but soon.

7.2.8 Discussion of survey

The sample size for the survey were only 10 persons, all students at the Institute of Information and Media Science, but with different age, projects, knowledge of retail, IoT and beacons. Many of my co-students has above averagely technical capabilities and interests, and many of them are typical early adopters of new products. Which do make them a typical initial user group for apps using new technology. It is not claimed that the data produced hold for the general population, but I argue that it gives sufficient indications to say something in regard to the research questions. One could also argue that they have more knowledge of what the situation with data collection looks like today, than the average Joe. In which one would expect them to be amongst the more privacy issues-aware persons in their age group, the results do although show a somewhat different story. This is an interesting topic one could further investigate, why it seems that some are very concerned whilst others might not seem to care too much about who has data and personal information about them.

7.2.9 Conclusion of survey

The survey showed that people liked the overall idea, and they found most of the concepts helpful. In regard to RQ2, which asks if Stass and systems like it would be helpful to the customers and whether or not the customers would use such an app, it seems that the general consensus of the participants are yes. But there are issues present, and expansion and improvement from the concept presented in this thesis is necessary. There was also helpful input in regards to RQ3, which asks what kind of functionality systems like Stass could have.

8 Conclusion

To answer RQ1, which asks if BLE beacon provide sufficient technological basis for micro-location in retail store, the final answer were no. Even though through the experiments it was established that there have been improvements from the predecessor's experiment, it still is not sufficient. Accuracy positioning based solely on BLE like what is needed for optimal and smooth blue-dot navigation is not recommended, at least not for the current iteration of the technology. For proximity applications and for providing a physical world context to the digital devices however, it does suffice.

RQ2 seeks to answer whether systems like Stass would be helpful for the customers of retail stores, and if the customers would use such an app and system. To answer RQ2 an interview with an expert in the retail domain were conducted, and a survey consisting of a short interview and questionnaires for ten fellow students who can be considered as experts in the IT domain were conducted. The findings showed that the interviewees generally believed that there was value in an app like Stass, and that it would be able to help its users. It was also found that most of the interviewees would use an app like Stass, but throughout the research it became clear that there are issues to be addressed on subjects like privacy.

RQ3 is about identifying and figuring out what functionality is possible to have in a system like Stass, when utilizing the retail stores existing data and the data it potentially can get. Multiple functionalities and concepts that could prove useful were found through various channels. The channels being the literature review, investigating what exists in the industry, interviews, questionnaires, development and the ideas that I had which made me pursue the themes of this thesis.

The research problem addresses the increased competition many retail stores face from online stores, many of these stores and especially the larger chains have their own online store as well. During the work with the thesis it became apparent to me that some products people want to be able to physically interact with, which means that some stores are likely less affected by online shopping than others. Even though the situations for some of these stores might be less severe than my initial belief, I strongly believe that retail stores and their customers would benefit from increased use of digital solutions like those presented in this thesis.

Electronic Shelf Labels with BLE is a technology I in the end see as one of the most intriguing solution and enabler. The retail stores already buy and use ESLs due to all the benefits, and therefore incentive for the retail stores to invest in this is already present. The possibilities that opens when adding BLE, which are many, provide additional incentives. A store with such ESLs deployed all over, would more or less have everything needed to be able to create a system that implement the concepts that is depicted and presented in this thesis. I hypothesize that it could also provide such dense coverage that blue-dot navigation based on proximity and micro-location (rather than micro-positioning) might be achievable.

9 Bibliography

All references were last accessed 30.05.2018.

Bibliography

Abowd, G. and Mynatt, E. (2000). Charting Past, Present, and Future Research in Ubiquitous Computing.
Available from: http://doi.org/10.1145/344949.344988.

Amazon (2017). Amazon.com : Amazon Go.
Available from: https://www.amazon.com/b?node=16008589011.

Apple (2014). Getting Started with iBeacon Getting Started with iBeacon Overview.
Available from: https://developer.apple.com/ibeacon/Getting-Started-with-iBeacon.pdf.

Aruba (2017). Solution overview the evolution of the digital workplace.
Available from: http://www.arubanetworks.com/assets/so/SO_SmartWorkplace.pdf.

Bekkelien, A., Deriaz, M., and Marchand-Maillet, S. (2012). Bluetooth Indoor Positioning.
Available from: https://pdfs.semanticscholar.org/1919/037541b4a84d0b5a6dd4d425c0891282ae8f.pdf.

Bishop, T. (2018). Amazon Go is finally a go: Sensor-infused store opens to the public Monday, with no checkout lines – GeekWire.
Available from: https://www.geekwire.com/2018/check-no-checkout-amazon-go-automated-retail-store-will-finally-open-public-monday/.

Bluetooth SIG (2008). Bluetooth SIG to unveil Low Energy prototype at Wireless Japan 2008 — Bluetooth Technology Website.
Available from: https://www.bluetooth.com/news/pressreleases/2008/07/15/bluetooth-sig-to-unveil-low-energy-prototype-at-wireless-japan-2008.

Bluetooth SIG (2011). Bluetooth Smart Announcement.
Available from: https://web.archive.org/web/20150203053330/http://www.bluetooth.com/Pages/Press-Releases-Detail.aspx?ItemID=138.

Boyle, A. (2016). Ready to be tracked at the grocery store? Amazon's mini-mart raises new questions for digital privacy – GeekWire.
Available from: https://www.geekwire.com/2016/ready-tracked-grocery-store-amazons-mini-mart-new-frontier-digital-privacy/.

Bryman, A. (2016). *Social research methods*. Oxford University Press, Oxford, 5th ed. edition.

Campbell, M. (2015). Apple indoor positioning app 'Indoor Survey' spotted on iOS App Store.
Available from: `http://appleinsider.com/articles/15/11/02/apple-indoor-positioning-app-indoor-survey-spotted-on-ios-app-store`.

Chiang, K.-W., Liao, J.-K., Tsai, G.-J., and Chang, H.-W. (2015). The Performance Analysis of the Map-Aided Fuzzy Decision Tree Based on the Pedestrian Dead Reckoning Algorithm in an Indoor Environment.
Available from: `http://doi.org/10.3390/s16010034`.

Chiu, C. C., Hsu, J. C., and Leu, J. S. (2016). Implementation and analysis of hybrid wireless indoor positioning with ibeacon and wi-fi.
Available from: `http://doi.org/10.1109/ICUMT.2016.7765336`.

Chizari, A., Jamali, M. V., Abdollahramezani, S., Salehi, J. A., and Dargahi, A. (2017). Visible light for communication, indoor positioning, and dimmable illumination: A system design based on overlapping pulse position modulation.
Available from: `http://doi.org/10.1016/j.ijleo.2017.08.003`.

Condliffe, J. (2015). Apple's Indoor Survey App Creates Building Interior Maps Using an iPhone.
Available from: `https://gizmodo.com/apples-indoor-survey-app-creates-building-interior-maps-1739997097`.

Connell, C. (2015). What's The Difference Between Measuring Location By UWB, Wi-Fi, and Bluetooth?
Available from: `http://www.electronicdesign.com/communications/what-s-difference-between-measuring-location-uwb-wi-fi-and-bluetooth`.

Datatilsynet (2017). Sjekkliste for innebygd personvern.
Available from: `https://www.datatilsynet.no/globalassets/global/skjema-maler/sjekkliste-for-innebygd-personvern.pdf`.

Davis, A. (1992). Operational prototyping: a new development approach.
Available from: `http://doi.org/10.1109/52.156899`.

Deak, G., Curran, K., and Condell, J. (2012). A survey of active and passive indoor localisation systems.
Available from: `http://doi.org/10.1016/j.comcom.2012.06.004`.

Delfa, G. L. and Catania, V. (2014). Accurate indoor navigation using smartphone, bluetooth low energy and visual tags.
Available from: `https://www.semanticscholar.org/paper/Accurate-indoor-navigation-using-Smartphone%2C-Low-Delfa-Catania/5151d3b2f8e40e09853ea81506a62c854b63a129`.

Displaydata (2016). Displaydata - Labels animation video on Vimeo.
Available from: https://vimeo.com/168044813.

Estimote (2017a). Estimote Automapping with UWB Location Beacons – Estimote Community Portal.
Available from: https://community.estimote.com/hc/en-us/articles/115000106432-Estimote-Automapping-with-UWB-Location-Beacons.

Estimote (2017b). Reality matters — Estimote Beacons with UWB and automapping are now shipping.
Available from: http://blog.estimote.com/post/160804360410/estimote-beacons-with-uwb-and-automapping-are-now.

Estimote (2017c). Reality matters — Estimote Beacons with UWB can now automatically create floor plans.
Available from: http://blog.estimote.com/post/154460651570/estimote-beacons-with-uwb-can-now-automatically.

Estimote (2018a). Technical specification of Estimote Beacons and Stickers – Estimote Community Portal.
Available from: https://community.estimote.com/hc/en-us/articles/204092986-Technical-specification-of-Estimote-Beacons-and-Stickers.

Estimote (2018b). Why should I use Proximity SDK? What are the benefits? – Estimote Community Portal.
Available from: https://community.estimote.com/hc/en-us/articles/204100866-Why-should-I-use-Proximity-SDK-What-are-the-benefits-.

European Parliament (2016). General Data Protection Regulation.
Available from: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2016:119:FULL.

Fernández, T. M., Rodas, J., Escudero, C. J., and Iglesia, D. I. (2007). Bluetooth sensor network positioning system with dynamic calibration.
Available from: http://doi.org/10.1109/ISWCS.2007.4392299.

Fernando, M. J. E., Shurane, S. S., Wijesinghe, L. S., Thenuwara, N. M., and Dhammearatchi, D. (2016). Pick My Dress: Beacon based Navigation System to find your Suitable Wear.
Available from: http://www.ijcaonline.org/archives/volume154/number1/fernando-2016-ijca-912020.pdf.

Godoy, S. (2017). Bluetooth Low Energy Beacon Performance and Utility in a Physical Retail Store Setting.
Available from: http://bora.uib.no/handle/1956/17344.

Google (2017a). Application Fundamentals — Android Developers.
Available from: https://developer.android.com/guide/components/fundamentals.html.

Google (2017b). Eddystone format — Beacons — Google Developers.
Available from: https://developers.google.com/beacons/eddystone.

Google (2017c). Map Objects - Indoor Maps — Google Maps Android API — Google Developers.
Available from: https://developers.google.com/maps/documentation/android-api/map#indoor_maps.

Google (2018a). Android P Features and APIs — Android Developers.
Available from: https://developer.android.com/preview/features.html.

Google (2018b). Documentation — Firebase.
Available from: https://firebase.google.com/docs/.

Google (2018c). Meet Android Studio — Android Studio.
Available from: https://developer.android.com/studio/intro/index.html.

Graube, N., Jarvis, M., Tarlow, B., and Gibbs, S. (2013). Method for setting up a beacon network inside a retail environment - US Patent: 9245160B2.
Available from: https://patents.google.com/patent/US9245160B2.

Haagmans, G. G., Verhagen, S., Voûte, R. L., and Verbree, E. (2017). A statistical analysis on the system performance of a Bluetooth Low Energy Indoor Positioning System in a 3D environment.
Available from: http://doi.org/10.5194/isprs-annals-IV-2-W4-319-2017.

Harle, R. and Faragher, R. (2014). An Analysis of the Accuracy of Bluetooth Low Energy for Indoor Positioning Applications.
Available from: https://www.semanticscholar.org/paper/An-Analysis-of-the-Accuracy-of-Bluetooth-Low-Energy-Faragher-Harle/bcbf261b0c98b563b842313d02990e386cad0d24.

Harrop, P. and Das, R. (2014). Mobile Phone Indoor Positioning Systems (IPS) and Real Time Locating Systems (RTLS) 2014-2024: IDTechEx.
Available from: https://www.idtechex.com/research/reports/mobile-phone-indoor-positioning-systems-ips-and-real-time-locating-systems-rtls-2014-2024-000359.asp.

Hearndon, S. L. (2016). An Analysis of Bluetooth Low Energy in the Context of Intermittently Powered Devices.
Available from: http://tigerprints.clemson.edu/all_theses/2537.

Heater, B. (2017). Apple Maps gets indoor mapping for more than 30 airports — TechCrunch.
Available from: https://techcrunch.com/2017/12/14/apple-maps-gets-indoor-mapping-for-more-than-30-airports/.

Hellevik, O. (2000). *Forskningsmetode i sosilogi og statsvitenskap*. Universitetsforlaget, Oslo, 2. edition.

Hevner, A. and Chatterjee, S. (2010). *Design Research in Information Systems*, volume 22 of *Integrated Series in Information Systems*. Springer US, Boston, MA.

Hevner, A. R., March, S. T., Park, J., and Ram, S. (2004). Design Science In Information Systems Research.
Available from: https://www.semanticscholar.org/paper/Design-Science-in-Information-Systems-Research-1-Hevner-Park/a555c8e9904b87ddec848f81bafb0fe5d8da458b.

Holger, K. and Willig, A. (2006). Localization and Positioning.
Available from: http://doi.org/10.1002/0470095121.ch9.

Hu, S., Fu, Y., She, C., and Yao, H. (2012). Enabling Zigbee Communications in Android Devices.
Available from: http://doi.org/10.2991/iccia.2012.159.

Hwang, I. and Jang, Y. J. (2017). Process Mining to Discover Shoppers' Pathways at a Fashion Retail Store Using a WiFi-Base Indoor Positioning System.
Available from: http://doi.org/10.1109/TASE.2017.2692961.

Iivari, J. (2015). Distinguishing and contrasting two strategies for design science research.
Available from: http://doi.org/10.1057/ejis.2013.35.

IndoorAtlas (2017). IndoorAtlas MappingGuide.
Available from: http://docs.indooratlas.com/MappingGuideEN.pdf.

Intel (2004). Ultra-Wideband (UWB) Technology Enabling high-speed wireless personal area networks.
Available from: http://www.usb.org/wusb/docs/Ultra-Wideband.pdf.

Ionescu, G., de la Osa, C., and Deriaz, M. (2014). Improving Distance Estimation in Object Localisation with Bluetooth Low Energy.
Available from: https://www.semanticscholar.org/paper/Improving-Distance-Estimation-in-Object-with-Low-Ionescu-Deriaz/00d91bef6cc54d080e01b4895c2423f6522807e0.

James, M. (2017). Indoor location signalling via light fittings - US Patent: 9644973.
Available from: https://patents.google.com/patent/US9644973.

Ji, M., Kim, J., Jeon, J., and Cho, Y. (2015). Analysis of positioning accuracy corresponding to the number of ble beacons in indoor positioning system.
Available from: http://doi.org/10.1109/ICACT.2015.7224764.

Jiménez, A. R. and Seco, F. (2016). Comparing Decawave and Bespoon UWB location systems: indoor/outdoor performance analysis.
Available from: http://doi.org/10.1109/IPIN.2016.7743686.

Kadous, W. and Peterson, S. (2013). Google I/O 2013 - The Next Frontier: Indoor Maps - YouTube.
Available from: https://www.youtube.com/watch?v=oLOUXNEcAJk.

Kanaris, L., Kokkinis, A., Liotta, A., and Stavrou, S. (2017). Fusing Bluetooth Beacon Data with Wi-Fi Radiomaps for Improved Indoor Localization.
Available from: http://doi.org/10.3390/s17040812.

Kerpelman, T. (2017). The Firebase Blog: Cloud Firestore for Realtime Database Developers.
Available from: https://firebase.googleblog.com/2017/10/cloud-firestore-for-rtdb-developers.html.

Korona, M., Mandi, M., Peji, V., and Siladi, D. (2015). Bluetooth Indoor Positioning.
Available from: http://drustvo-evo.hr/s3/files/webreports/2015/s3/Bluetooth_indoor_positioning.pdf.

Lazik, P., Rajagopal, N., and Rowe, A. (2014). Visual Light Landmarks for Mobile Devices.
Available from: http://doi.org/10.1109/IPSN.2014.6846757.

Lazik, P., Rajagopal, N., Shih, O., Sinopoli, B., and Rowe, A. (2015). ALPS: A Bluetooth and Ultrasound Platform for Mapping and Localization.
Available from: http://doi.org/10.1145/2809695.2809727.

Lazik, P. and Rowe, A. (2012). Indoor Pseudo-ranging of Mobile Devices using Ultrasonic Chirps.
Available from: http://doi.org/10.1145/2426656.2426667.

Li, Z., Yang, A., Lv, H., Feng, L., and Song, W. (2017). Fusion of Visible Light Indoor Positioning and Inertial Navigation Based on Particle Filter.
Available from: http://doi.org/10.1109/JPHOT.2017.2733556.

Lin, X.-Y., Ho, T.-W., Fang, C.-C., Yen, Z.-S., Yang, B.-J., and Lai, F. (2015). A Mobile Indoor Positioning System Based on iBeacon Technology.
Available from: http://doi.org/10.1109/EMBC.2015.7319507.

Liu, Y., Dashti, M., Abd Rahman, M. A., and Zhang, J. (2014). Indoor localization using smartphone inertial sensors.
Available from: http://doi.org/10.1109/WPNC.2014.6843288.

Lunden, I. (2018). Here acquires Micello to add indoor mapping as part of its IoT business unit — TechCrunch.
Available from: https://techcrunch.com/2018/01/24/here-acquires-micello-to-add-indoor-mapping-as-part-of-its-iot-business-unit/.

Mackey, A. and Spachos, P. (2017). Performance Evaluation of Beacons for Indoor Localization in Smart Buildings.
Available from: http://doi.org/10.1109/GlobalSIP.2017.8309075.

Oates, B. J. (2006). *Researching information systems and computing*. Sage Publications, London.

Panzarino, M. (2013). What is WiFiSLAM and Why Did Apple Want It?
Available from: https://thenextweb.com/apple/2013/03/26/what-exactly-wifislam-is-and-why-apple-acquired-it/.

Pei, L., Liu, J., Chen, Y., Chen, R., and Chen, L. (2017). Evaluation of fingerprinting-based WiFi indoor localization coexisted with Bluetooth.
Available from: http://doi.org/10.1186/s41445-017-0008-x.

Peiris, K. A. D. K. N., Asmina, S. A., Amarasinghe, A. A. T. K. K., Gunawardhane, C. N., and Dhammearatchi, D. (2016). SHOP&NAV: iBeacon based indoor assistance and Navigation System.
Available from: http://www.ijsrp.org/research-paper-1116.php?rp=P595956.

Peterson, R. (2000). Constructing Effective Questionnaires.
Available from: http://doi.org/10.4135/9781483349022.

PhoneArena (2011). Google Maps 6.0 with indoor navigation overview - YouTube.
Available from: https://www.youtube.com/watch?v=cPsTWj_O3Qs.

Pricer (2017). Shelf-Edge Digital Solutions.
Available from: http://www.pricer.com/Global/PricerDigitalShelf-EdgeSolutions_RETABREN17-03-1-web.pdf.

Puerini, G. L., Kunmar, D., and Kessel, S. (2014). Transitioning items from a materials handling facility - US Patent: 20150012396A1.
Available from: https://patents.google.com/patent/US20150012396A1/.

Rose, J. and Gamble, J. G. (2005). Human Walking.
Available from: http://ebookcentral.proquest.com/lib/bergen-ebooks/detail.action?docID=2032509.

Rosenberg, M. (2018). Cambridge Analytica Suspends C.E.O. Amid Facebook Data Scandal - The New York Times.
Available from: https://www.nytimes.com/2018/03/20/world/europe/cambridge-analytica-ceo-suspended.html.

Saetre, K. A. S. (2017). Bluetooth Low Energy Beacon Performance and Utility in a Car Location Memory Aid Setting.
Available from: http://bora.uib.no/handle/1956/17336.

Schechner, S. M. (2016). Beacon technology and the future/present state of e- commerce retail sales.
Available from: http://www.albanylawjournal.org/Documents/Articles/26.2.172_Schechner.pdf.

Sims, G. (2017). Why you won't be using Bluetooth 5 on your Galaxy S8 just yet - Gary explains - Android Authority.
Available from: https://www.androidauthority.com/bluetooth-5-samsung-galaxy-s8-774560/.

Skjetne, T. (2016). Using Bluetooth beacons to pay for metro tickets.
Available from: https://www.duo.uio.no/bitstream/handle/10852/51097/Torkjel-Skjetne-Masteroppgave-mai-2016.pdf?sequence=1.

Stackexchange.com (2015a). Difference between Positioning and Localization - Geographic Information Systems Stack Exchange.
Available from: https://gis.stackexchange.com/questions/106785/difference-between-positioning-and-localization.

Stackexchange.com (2015b). What is the difference between Positioning and Localization Systems - Robotics Stack Exchange.
Available from: https://robotics.stackexchange.com/questions/7221/what-is-the-difference-between-positioning-and-localization-systems.

Sterling, G. and Hegenderfer, S. (2014). Everything You Always Wanted To Know about Beacons — Webcast.
Available from: https://www.brighttalk.com/webcast/635/107617#/register.

Store Norske Leksikon (2017). Python – programmeringsspråk – Store norske leksikon.
Available from: https://snl.no/Python_-_programmeringsspr%C3%A5k.

Tippner, I. (2017). GeoBeacon's Github Page.
Available from: https://github.com/Tecno-World/GeoBeacon/blob/master/README.md.

Torstensson, D. (2016). Indoor Positioning System using Bluetooth beacon technology.
Available from: http://mdh.diva-portal.org/smash/get/diva2:1075574/FULLTEXT01.pdf.

Tsang, T. and El-Gamal, M. (2005). Ultra-wideband (UWB) communications systems: an overview.
Available from: http://doi.org/10.1109/NEWCAS.2005.1496688.

UXL Encyclopedia of Science 3rd ed. (Edited by Blackwell, Amy Hackney and Manar, Elizabeth) (2015). Prototype.
Available from: http://link.galegroup.com/apps/doc/ENKDZQ347975681/SCIC?u=dclib_main&sid=SCIC&xid=0c8f739d.

Vaishnavi, V. K. and Kuechler, W. L. (2004). Design Science Research in Information Systems.
Available from: http://www.desrist.org/design-research-in-information-systems/.

Vlugt, E. (2013). Bluetooth Low Energy, Beacons and Retail.
Available from: http://global-old.verifone.com/media/3603729/bluetooth-low-energy-beacons-retail-wp.pdf.

Wiig, T. F. (2010). Assesment of Indoor Positioning Systems (IPS) technology.
Available from: https://www.duo.uio.no/bitstream/handle/10852/8740/Wiig.pdf?sequence=4.

Yoshida, N. and Manandhar, D. (2017). IMES White Paper.
Available from: http://gnss.co.jp/wp-content/uploads/2017/04/IMES_WhitePaper_20170426.pdf.

Zafari, F. and Papapanagiotou, I. (2015). Enhancing ibeacon based micro-location with particle filtering.
Available from: http://doi.org/10.1109/GLOCOM.2015.7417504.

Zafari, F., Papapanagiotou, I., and Christidis, K. (2016). Micro-location for Internet of Things equipped Smart Buildings.
Available from: http://doi.org/10.1109/JIOT.2015.2442956.

Zaragozí, B., Font, P., Navarro, J., Amorós, A., Ramon Morte, A., and Belda-Antolí, A. (2015). A proposal for design and implementation of an hybrid navigation system based on open data, augmented reality and big data applications for the smart cities.
Available from: http://doi.org/10.13140/RG.2.1.4869.2648.

Zhao, X., Ruan, L., Zhang, L., Long, Y., and Cheng, F. (2018). An Analysis of the Optimal Placement of Beacon in Bluetooth-INS Indoor Localization An Analysis of the Optimal Placement of Bea- con in Bluetooth-INS Indoor Localization.
Available from: http://doi.org/10.3929/ethz-b-000225588.

Zhou, F. (2017). A Survey of Mainstream Indoor Positioning Systems.
Available from: http://doi.org/10.1088/1742-6596/910/1/012069.

Zhu, J., Zeng, K., Kim, K.-H., and Mohapatra, P. (2012). Improving Crowd-Sourced Wi-Fi Localization Systems using Bluetooth Beacons.
Available from: http://doi.org/10.1109/SECON.2012.6275790.

Zhuang, W., Shen, X., and Bi, Q. (2003). Ultra-wideband wireless communications. Available from: http://doi.org/10.1002/wcm.149.

Zhuang, Y., Yang, J., Li, Y., Qi, L., and El-Sheimy, N. (2016). Smartphone-Based Indoor Localization with Bluetooth Low Energy Beacons. Available from: http://doi.org/10.3390/s16050596.

10 Appendix A

10.1 The informed consent form for the interview and survey

The attachment is on the next page(s).

Informed consent form interview and user-tests

Institution responsible for research project: University of Bergen
Project ending: May 2018
Anonymization of data: May 2018

Introduction

Stass is a prototype application illustrating some of the principles that will be the topic of discussion, namely what does the subjects think regarding digitalization and technological advances within the store-domain.

Eligibility to participate in this interview/user-test?

You have knowledge and experience from the retail-industry, stores or warehouses.
You have a general technical aptitude and have used an android application before.

Practical information
If you agree to be in this interview/testing, you will be asked to some of the following:
1. Share knowledge and thoughts regarding the state of the retail-industry today
2. Look at specifics of what technology has done and can do for the retail-industry
3. Participate in tests where you will try the prototype app in a simulated situation.
4. Give feedback on the tests and prototype in a short semi structured interview.

Participation in this study will be a 30 minutes to 1 hour session.

There are no known risks associated with your participation in this research beyond those of everyday life.

Your responses will be kept confidential by the researcher.

Participation in this study is voluntary. You may refuse to participate or withdraw at anytime without penalty.

For interviews, questionnaires, or surveys, you have the right to skip or not answer any questions you prefer not to answer.

Participants will be referred to anonymously in the final delivery of the research paper.

______________ ______________

Subject Kristian Hellum

10.2 The Questionnaire

The attachment is on the next page(s).

Questionnaire - Stass

Stass (STore ASSistant)

The questionnaire consists of three parts:

The first part consists of personals.
The second part consists of shorter questions (on a scale and yes/no questions).
In the third part you get the opportunity to go into more detail.

*Må fylles ut

Personals and approval of consent form

1. **I consent that this contribution can be anonymized and used in the thesis, and I was given the consent form.** *

   Merk av for alt som passer

   - [ ] Yes
   - [ ] No

2. **What's your age?** *

   ____

3. **What's your gender?** *

   Markér bare én oval.

   - ( ) Female
   - ( ) Male
   - ( ) Other
   - ( ) Prefer not to say
   - ( ) Andre: ______________________________

4. **Approximately how many times per week do you visit a physical store?** *

   Any type of physical store, grocery, clothing, etc.

   ____

5. **Do you use any apps related to stores today?** *

   Markér bare én oval.

   - ( ) Yes
   - ( ) No

Short answers

This section has answers that are quick and easy to answer, be sure to read and understand the question properly!

6. **How likely is it that you would give up private information to get benefits like the ones from Stass in return? ***
Markér bare én oval.

	1	2	3	4	5	6	7	8	9	10	
Very unlikely											Very likely

7. **How concerned are you with who has access to data about you? ***
Markér bare én oval.

	1	2	3	4	5	6	7	8	9	10	
Not really concerned											Very concerned

8. **How likely is it that you would use an app like Stass? ***
Markér bare én oval.

	1	2	3	4	5	6	7	8	9	10	
Very unlikely											Very likely

9. **How helpful do you think systems like Stass would be to its users? ***
Markér bare én oval.

	1	2	3	4	5	6	7	8	9	10	
Not really helpful											Very helpful

10. **Have you in the past couple of years left a store without buying a product because you didn't find it? ***
Markér bare én oval.

- Yes
- No
- Not sure

11. **Do you think Stass and systems like it in some cases could be a sufficient alternative to getting assistance from a store employee? ***
Markér bare én oval.

- Yes
- No
- Not sure

Written answers

The answer doesn't need to be long, write what you feel is sufficent to explain your thoughts .
If you're having a hard time answering the questions, state so and move on.
Please use full sentences.

12. **Are there any kinds of products you wouldn't buy online? If yes, what kinds of products?** *

Markér bare én oval.

- No
- Andre: ____________________

13. **Is there any other problems you think an application like Stass could solve? If yes, what?** *

Markér bare én oval.

- No
- Andre: ____________________

14. **What would it take for you to allow data to be collected from your phone?** *

15. **If any, which of the features or concepts presented in Stass do you find especially promising?** *

16. **If any, which of the features or concepts presented in Stass do you find especially problematic?** *

17. **(Optional) Other thoughts on the project?**

18. **(Optional) Any comments on the questionnaire?**

10.3 The Questionnaire answers

The attachment is on the next page(s).

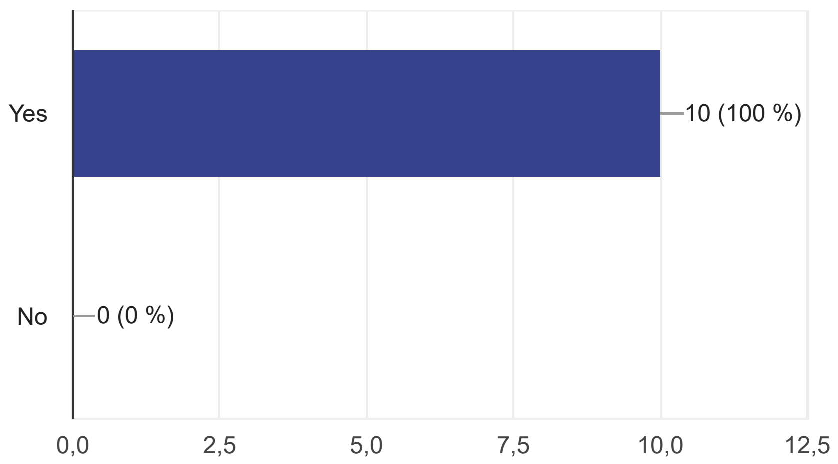
Questionnaire - Stass

10 svar

Personals and approval of consent form

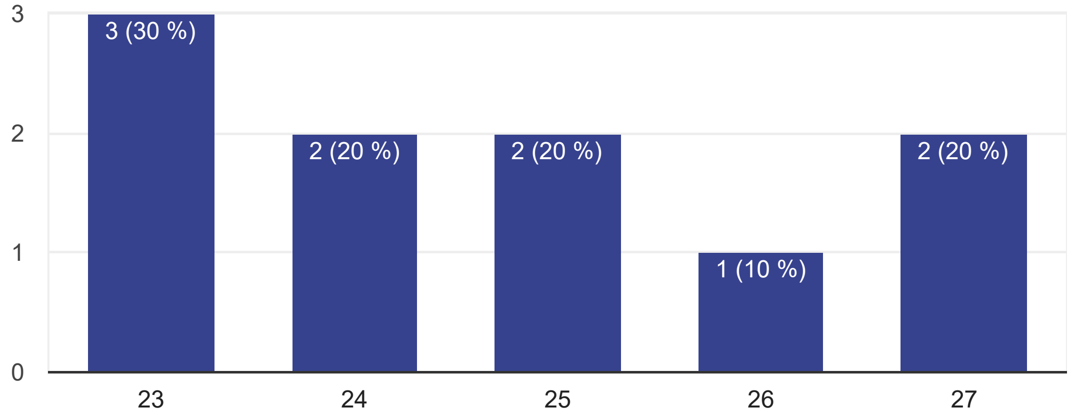
I consent that this contribution can be anonymized and used in the thesis, and I was given the consent form.

10 svar



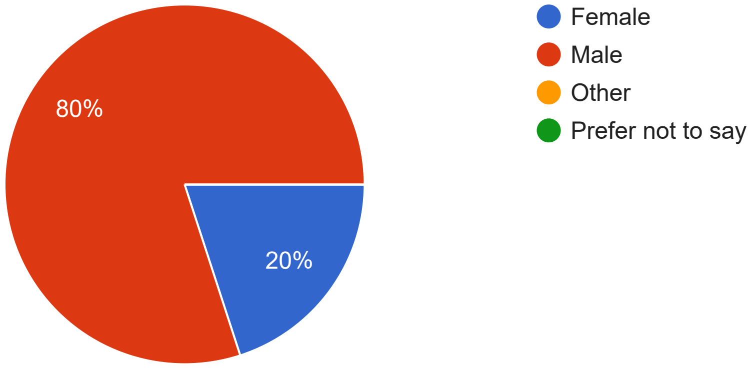
What's your age?

10 svar



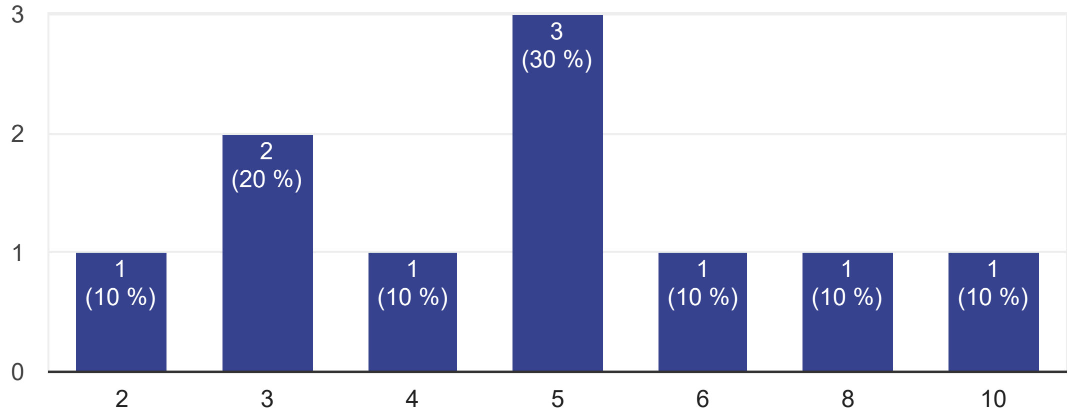
What's your gender?

10 svar



Approximately how many times per week do you visit a physical store?

10 svar



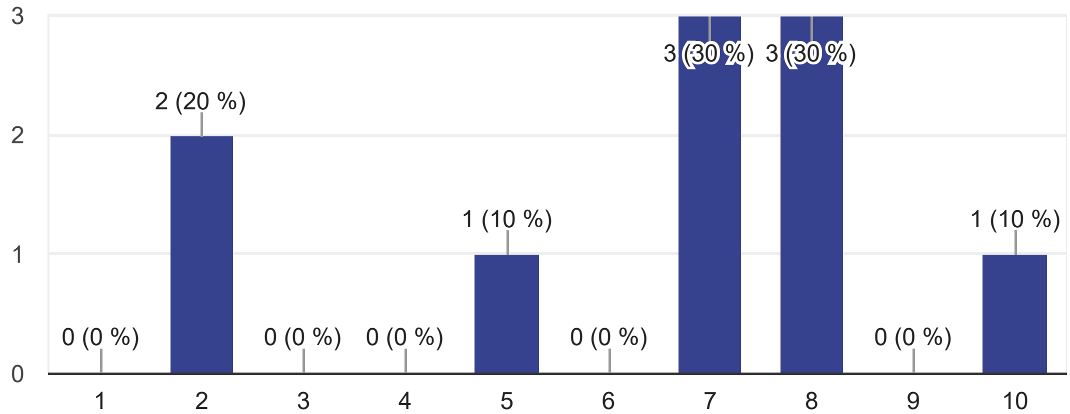
Do you use any apps related to stores today?

10 svar

Short answers

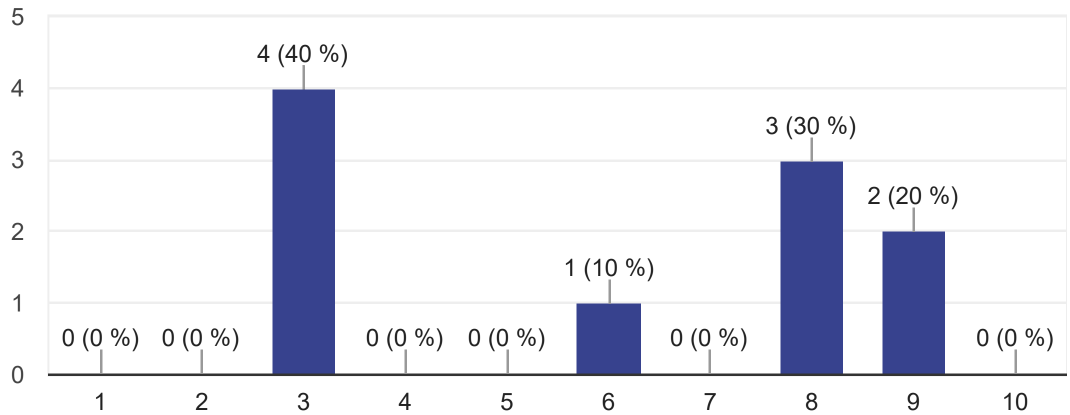
How likely is it that you would give up private information to get benefits like the ones from Stass in return?

10 svar



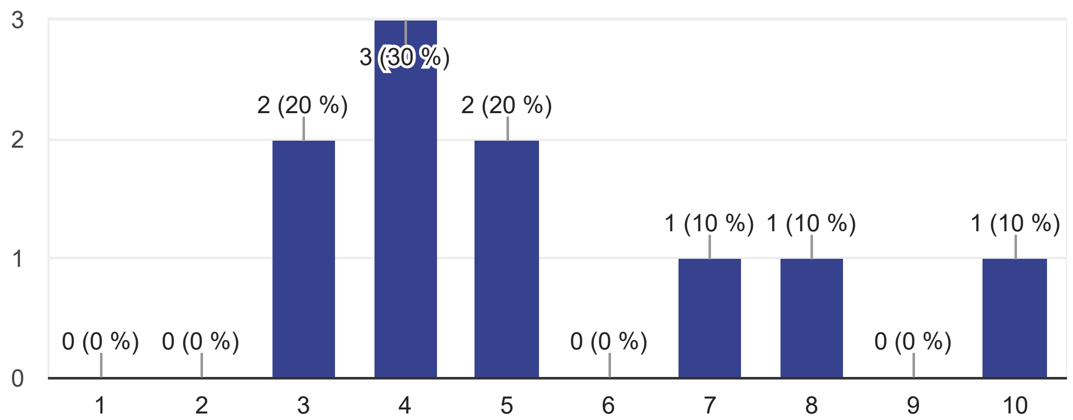
How concerned are you with who has access to data about you?

10 svar



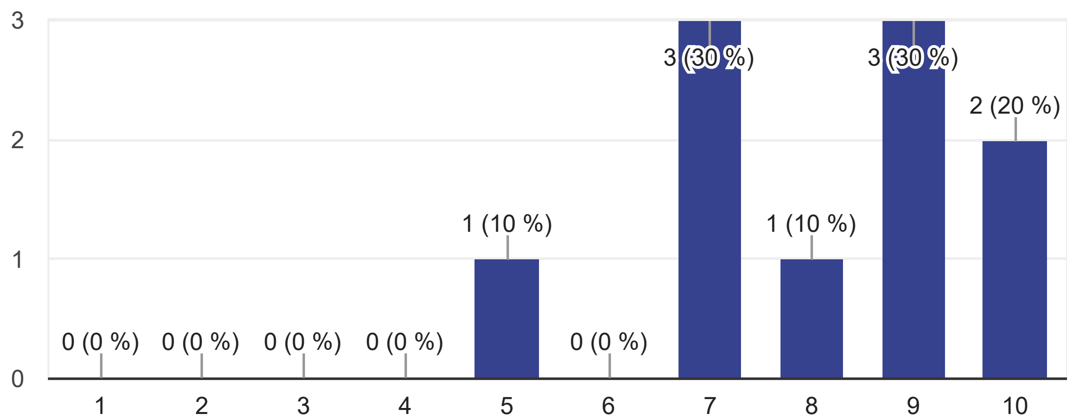
How likely is it that you would use an app like Stass?

10 svar



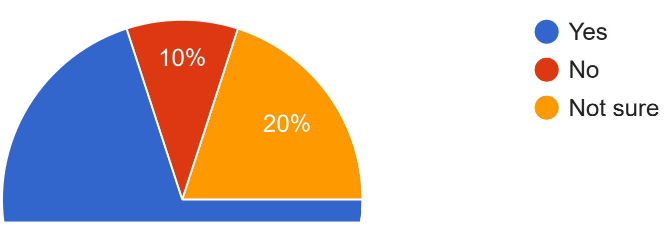
How helpful do you think systems like Stass would be to its users?

10 svar



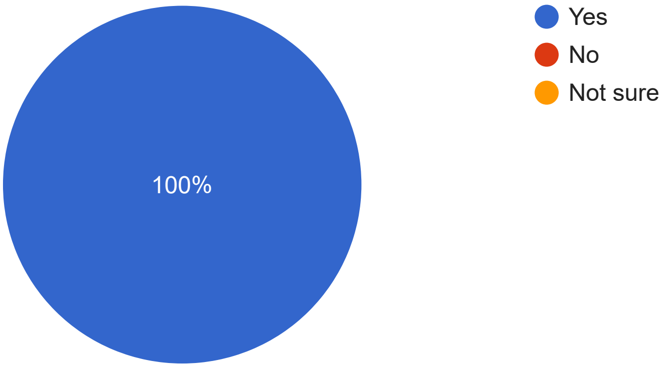
Have you in the past couple of years left a store without buying a product because you didn't find it?

10 svar



Do you think Stass and systems like it in some cases could be a sufficient alternative to getting assistance from a store employee?

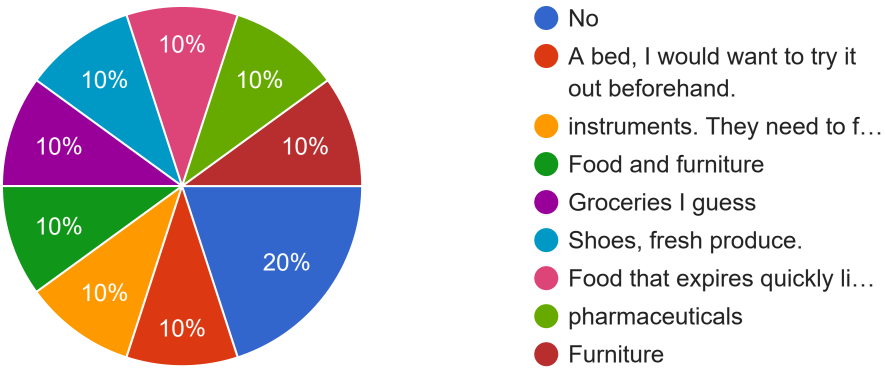
10 svar



Written answers

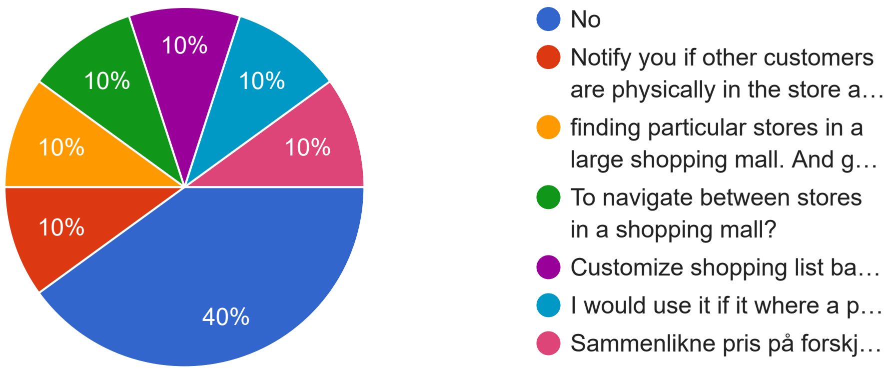
Are there any kinds of products you wouldn't buy online? If yes, what kinds of products?

10 svar



Is there any other problems you think an application like Stass could solve? If yes, what?

10 svar



What would it take for you to allow data to be collected from your phone?

10 svar

Nothing, I would like data to be collected if it helped me get better service and be more efficient in a store.

Depends on what data and what it is used for. The data needs to be collected in a clear and understandable manner. The user should be notified about what data is collected and what it is used for. It should only be collected when the app is in use.

I dont know.

Complete anonymization of collected data, no sharing / resale of data

If there is enough of a benefit for me, and it is clearly stated what the data is used for.

I would like to know how the data is going to be used and that they are stored in a secure way.

Not much, seeing as it already does it with other services.

I dont like single purpose application.

The app should not collect any more data than what is necessarry,

Helst anonymiseres.

If any, which of the features or concepts presented in Stass do you find especially promising?

10 svar

The paperless queue system. Letting me wander around in the shop without having to be worried that my spot in the queue will be taken.

the in-store navigation aspect

The app itself seems easy to navigate. The map seems very helpfull.

Store navigation, locating products

Barcode scanning for product information, pathfinding for stores you don't frequent and might have a hard time navigating.

I really like the idea of a map with the location of both me, and the product I am looking for. It would make it easier and quicker to do the shopping.

The navigation aspect, where it enables you to find the products.

Cloud Queue.

I find the product location feature promising,

Hjelp til å finne varer, og hjelp til å få informasjon om hvor jeg kan kjøpe varen jeg er ute etter hvis butikken jeg er i ikke har den

If any, which of the features or concepts presented in Stass do you find especially problematic?

10 svar

None, I think all the features are helping to solve a problem.

the collection of data. This needs careful consideration

Maybe the help-button. Because it seems that this potensially could take some time, so that while you walk around waiting for help, you will propably find your product.

Mining customer movement patterns

Battery life of phones with bluetooth on, perhaps... Nothing in particular comes to mind.

There are no aspects of the application I think of as especially problematic.

The customer service. It would probably be difficult for the employees to find the actual person in the queue.

Locations not being dynamicly updated. Custumers might move and look around if the queue is long etc.
Is it hard to incorporate changes in the structure of the stores? mapping etc.

Not really.

Ingen

(Optional) Other thoughts on the project?

3 svar

Seems bretty cool

When beacon/bluetooth technology matures more, there will probably be systems like this, sometime in the not too distant future.

Cool project, which I really would like to see developed further. I liked the UI.

(Optional) Any comments on the questionnaire?

1 svar

No comment.

10.4 Links to figures

Links to images that were not created, but rather borrowed from others.

Figure 3.2, Example of how one can structure the IDs to relate to the stores:
`https://developer.apple.com/ibeacon/Getting-Started-with-iBeacon.pdf`

Figure 3.3, Explanation of the intended purpose of the UUID, Major and Minor:
`https://developer.apple.com/ibeacon/Getting-Started-with-iBeacon.pdf`

Figure 3.4, Simple illustration from Estimote of how the ID flows in such systems:
`https://community.estimote.com/hc/en-us/articles/360002656512-How-beacons-work`

Figure 4.3, An example of attachment-based zones for the beacons and proximity:
`www.google.comhttps://github.com/Estimote/iOS-Proximity-SDK/raw/master/readme_images/demo_attachments.png`

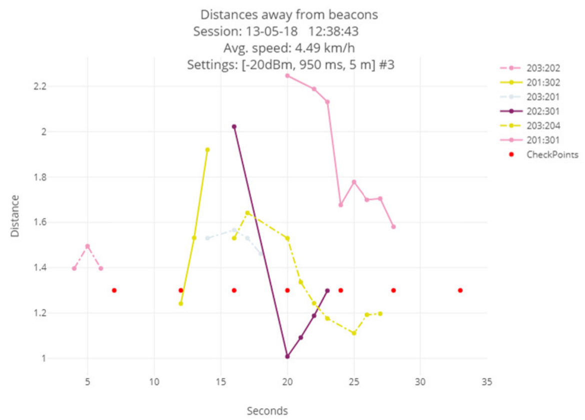
11 Appendix B

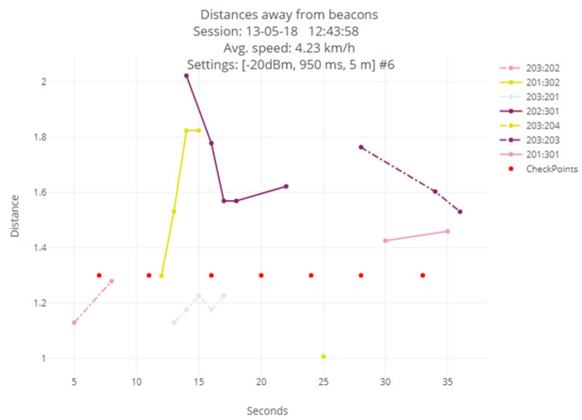
11.1 Beacon performance testing graphs

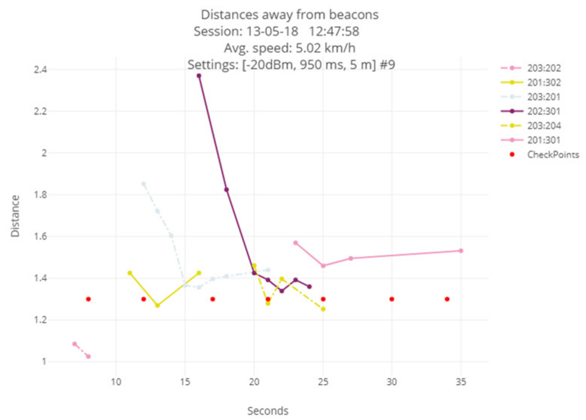
Graphs for each session, showing estimated distance, measured RSSI and estimated phone positions.

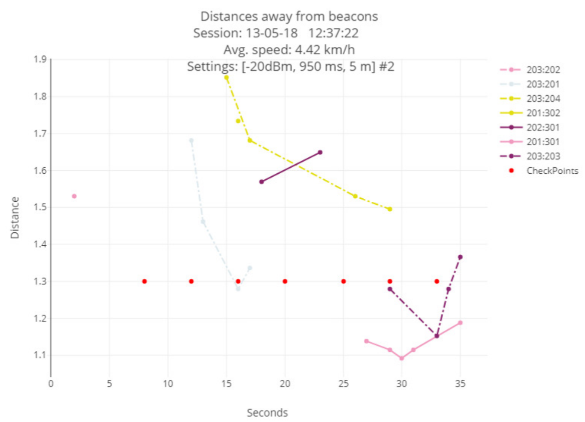
11.1.1 Distance graphs

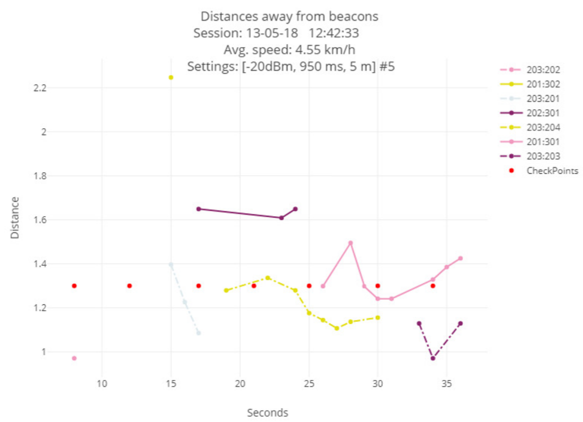
The attachment is on the next page(s).

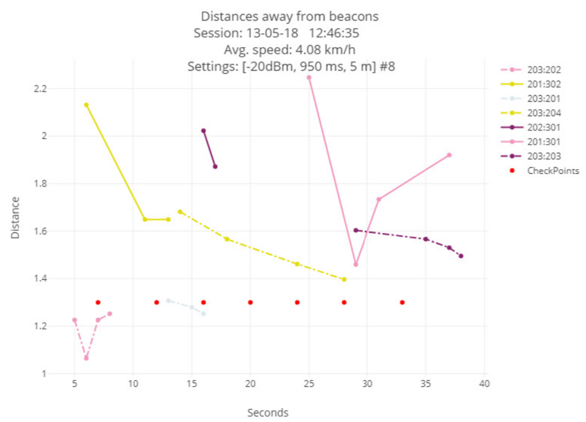

Distances away from beacons
Session: 13-05-18 12:38:43
Avg. speed: 4.49 km/h
Settings: [-20dBm, 950 ms, 5 m] #3
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
CheckPoints

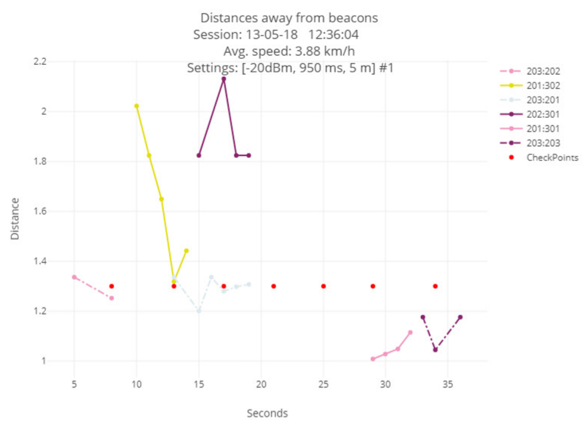

Distances away from beacons
Session: 13-05-18 12:43:58
Avg. speed: 4.23 km/h
Settings: [-20dBm, 950 ms, 5 m] #6
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
203:203
201:301
CheckPoints

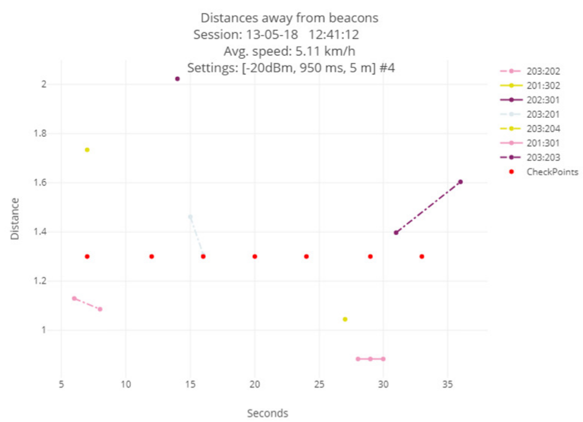

Distances away from beacons
Session: 13-05-18 12:47:58
Avg. speed: 5.02 km/h
Settings: [-20dBm, 950 ms, 5 m] #9
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
CheckPoints

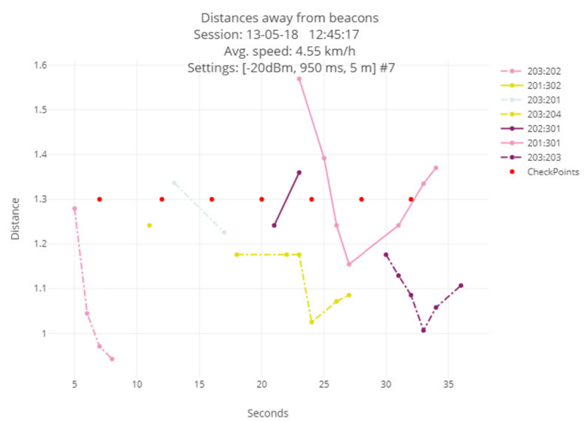

Distances away from beacons
Session: 13-05-18 12:37:22
Avg. speed: 4.42 km/h
Settings: [-20dBm, 950 ms, 5 m] #2
Distance
Seconds
203:202
203:201
203:204
201:302
202:301
201:301
203:203
CheckPoints

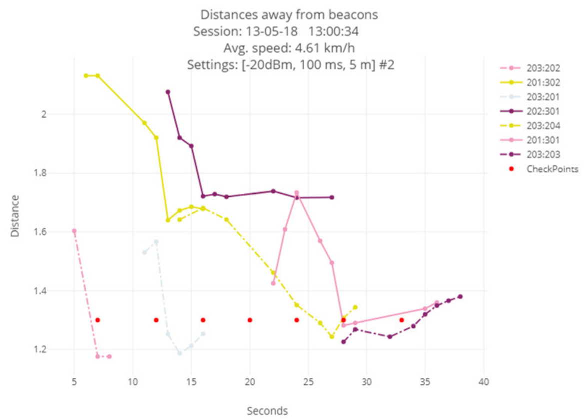

Distances away from beacons
Session: 13-05-18 12:42:33
Avg. speed: 4.55 km/h
Settings: [-20dBm, 950 ms, 5 m] #5
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints

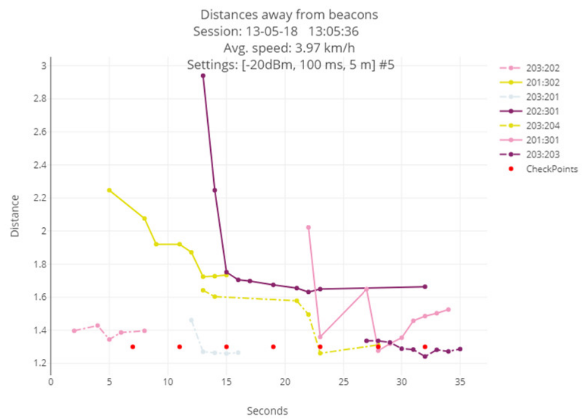

Distances away from beacons
Session: 13-05-18 12:46:35
Avg. speed: 4.08 km/h
Settings: [-20dBm, 950 ms, 5 m] #8
Distance
Seconds
203:202
201:302
203:201
203:204
202:301
201:301
203:203
CheckPoints

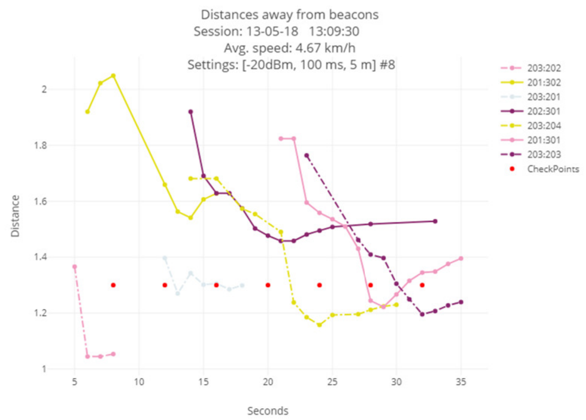

Distances away from beacons
Session: 13-05-18 12:36:04
Avg. speed: 3.88 km/h
Settings: [-20dBm, 950 ms, 5 m] #1
Distance
Seconds
203:202
201:302
203:201
202:301
201:301
203:203
CheckPoints

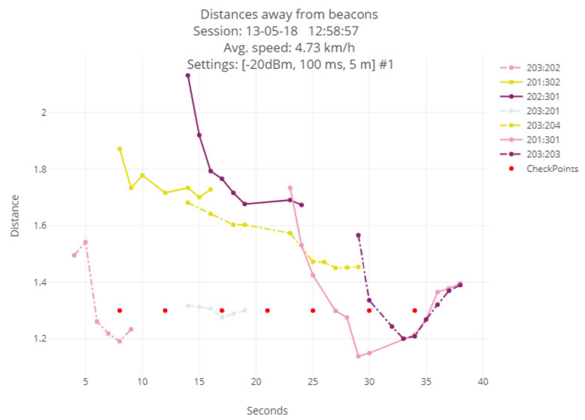

Distances away from beacons
Session: 13-05-18 12:41:12
Avg. speed: 5.11 km/h
Settings: [-20dBm, 950 ms, 5 m] #4
Distance
Seconds
203:202
201:302
202:301
203:201
203:204
201:301
203:203
CheckPoints

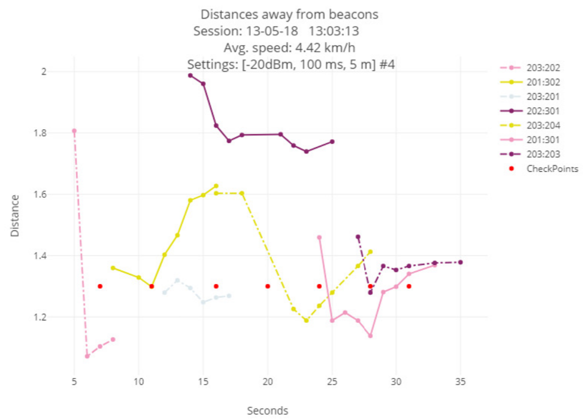

Distances away from beacons
Session: 13-05-18 12:45:17
Avg. speed: 4.55 km/h
Settings: [-20dBm, 950 ms, 5 m] #7
Distance
Seconds
203:202
201:302
203:201
203:204
202:301
201:301
203:203
CheckPoints

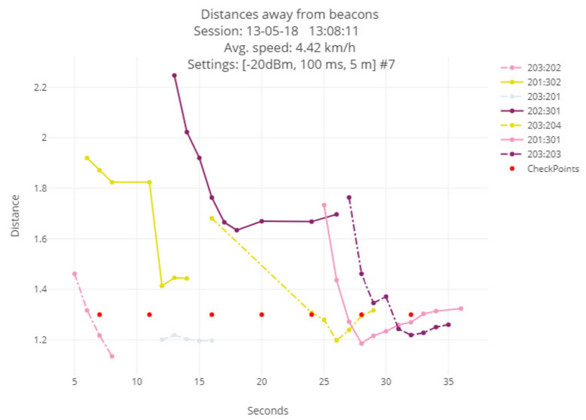

Distances away from beacons
Session: 13-05-18 13:00:34
Avg. speed: 4.61 km/h
Settings: [-20dBm, 100 ms, 5 m] #2
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints
Distance
Seconds

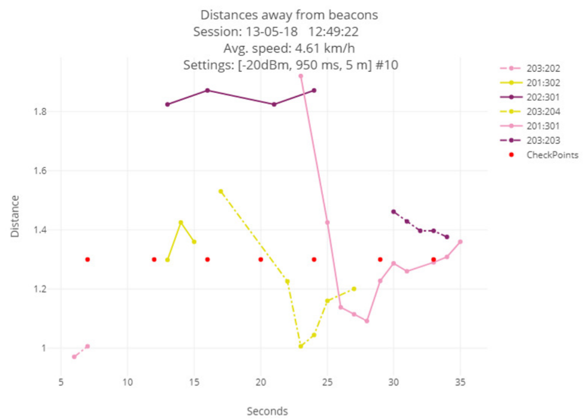

Distances away from beacons
Session: 13-05-18 13:05:36
Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 5 m] #5
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints
Distance
Seconds

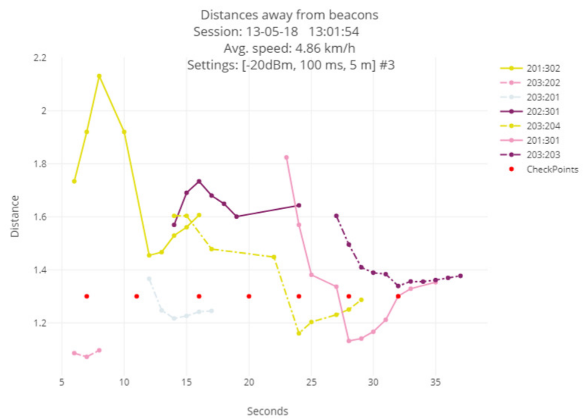

Distances away from beacons
Session: 13-05-18 13:09:30
Avg. speed: 4.67 km/h
Settings: [-20dBm, 100 ms, 5 m] #8
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints
Distance
Seconds

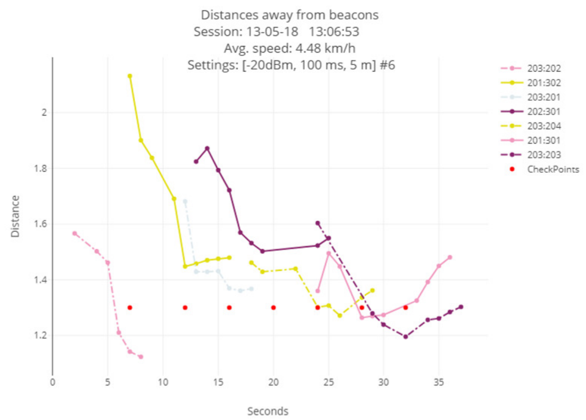

Distances away from beacons
Session: 13-05-18 12:58:57
Avg. speed: 4.73 km/h
Settings: [-20dBm, 100 ms, 5 m] #1
203:202
201:302
202:301
203:201
203:204
201:301
203:203
CheckPoints
Distance
Seconds

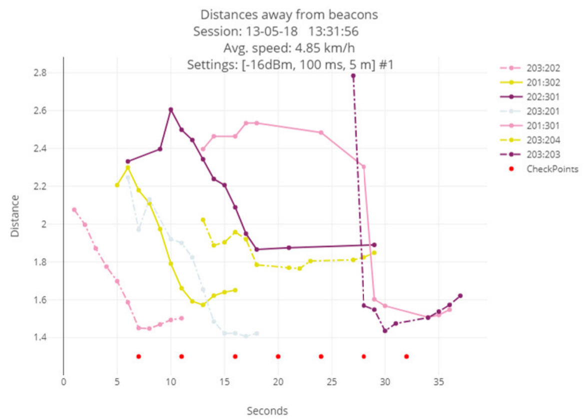

Distances away from beacons
Session: 13-05-18 13:03:13
Avg. speed: 4.42 km/h
Settings: [-20dBm, 100 ms, 5 m] #4
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints
Distance
Seconds


Distances away from beacons
Session: 13-05-18 13:08:11
Avg. speed: 4.42 km/h
Settings: [-20dBm, 100 ms, 5 m] #7
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints
Distance
Seconds


Distances away from beacons
Session: 13-05-18 12:49:22
Avg. speed: 4.61 km/h
Settings: [-20dBm, 950 ms, 5 m] #10
203:202
201:302
202:301
203:204
201:301
203:203
CheckPoints
Distance
Seconds


Distances away from beacons
Session: 13-05-18 13:01:54
Avg. speed: 4.86 km/h
Settings: [-20dBm, 100 ms, 5 m] #3
201:302
203:202
203:201
202:301
203:204
201:301
203:203
CheckPoints
Distance
Seconds


Distances away from beacons
Session: 13-05-18 13:06:53
Avg. speed: 4.48 km/h
Settings: [-20dBm, 100 ms, 5 m] #6
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints
Distance
Seconds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Avg. speed: 4.85 km/h
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Distance
Seconds
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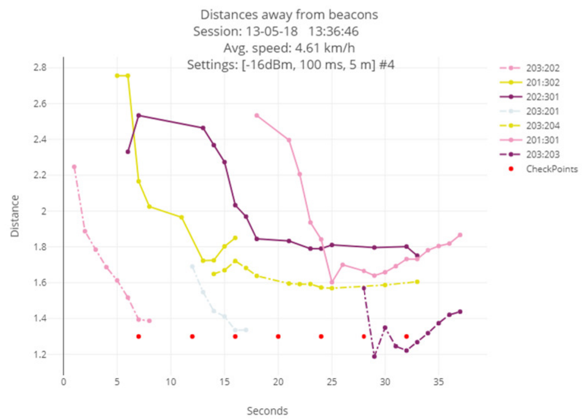
201:302
202:301
203:201
201:301
203:204
203:203
CheckPoints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Session: 13-05-18 13:36:46
Avg. speed: 4.61 km/h
Settings: [-16dBm, 100 ms, 5 m] #4
Distance
Seconds
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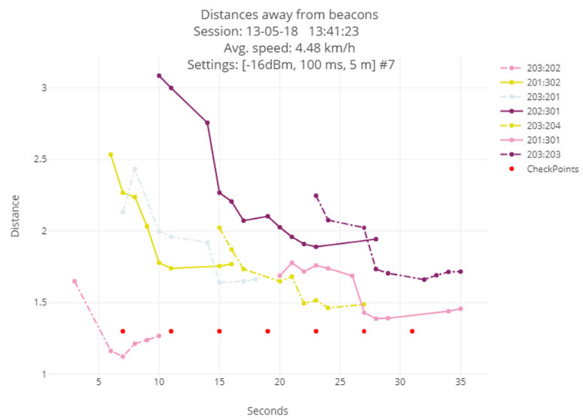
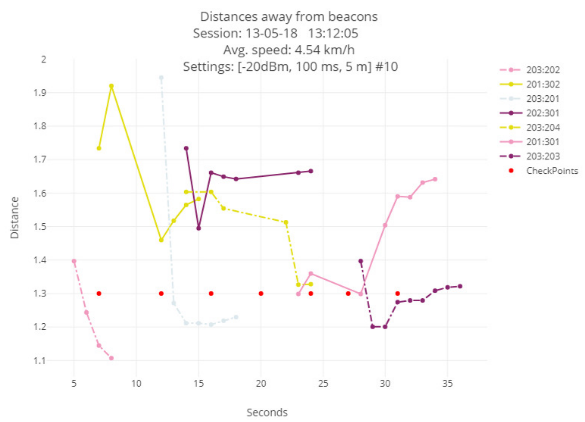
201:302
202:301
203:201
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 13:41:23
Avg. speed: 4.48 km/h
Settings: [-16dBm, 100 ms, 5 m] #7
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints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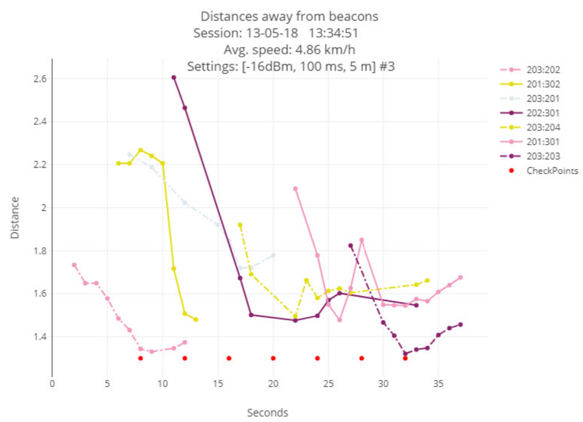
Session: 13-05-18 13:12:05
Avg. speed: 4.54 km/h
Settings: [-20dBm, 100 ms, 5 m] #10
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 13:34:51
Avg. speed: 4.86 km/h
Settings: [-16dBm, 100 ms, 5 m] #3
Distance
Seconds
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202:301
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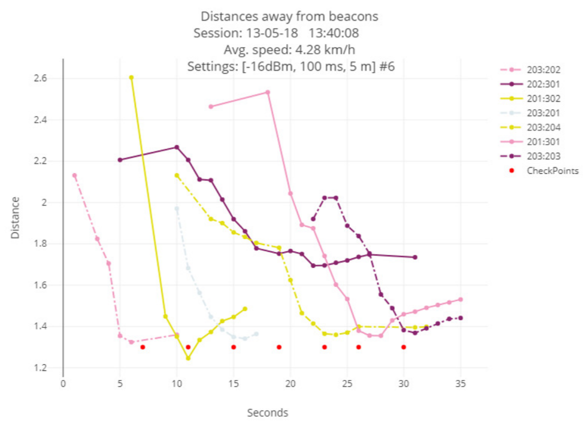
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 13:40:08
Avg. speed: 4.28 km/h
Settings: [-16dBm, 100 ms, 5 m] #6
Distance
Seconds
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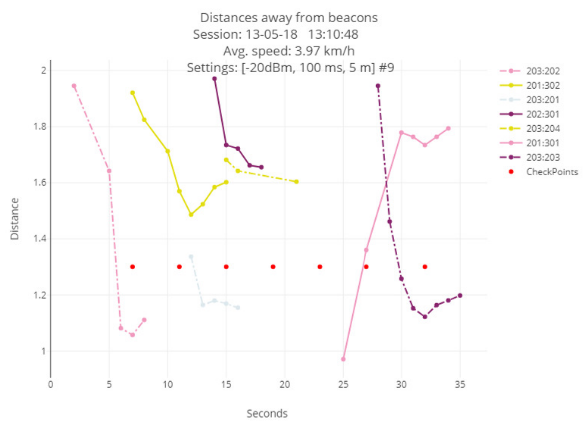
203:203
CheckPoints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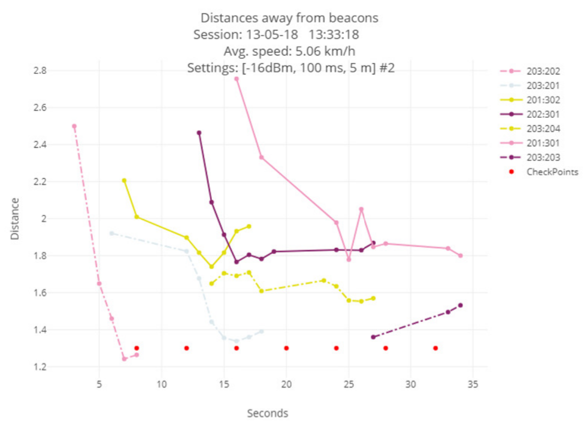
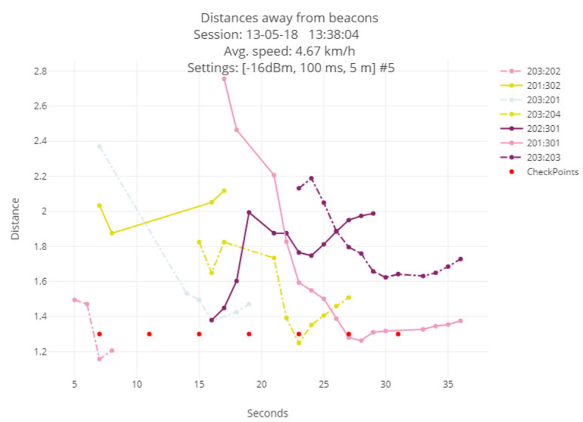
Session: 13-05-18 13:10:48
Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 5 m] #9
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 13:33:18
Avg. speed: 5.06 km/h
Settings: [-16dBm, 100 ms, 5 m] #2
Distance
Seconds
203:202
203:201
201:302
202:301
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 13:38:04
Avg. speed: 4.67 km/h
Settings: [-16dBm, 100 ms, 5 m] #5
Distance
Seconds
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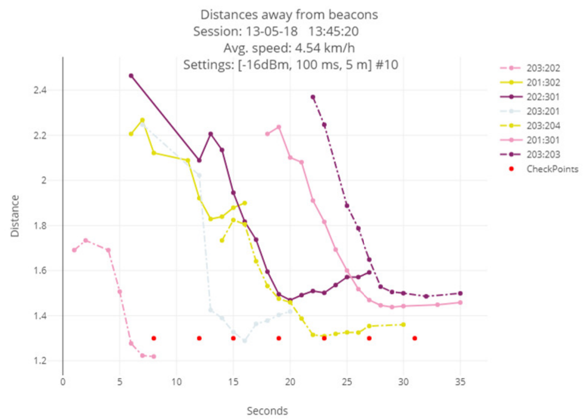
203:204
202:301
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 13:45:20
Avg. speed: 4.54 km/h
Settings: [-16dBm, 100 ms, 5 m] #10
Distance
Seconds
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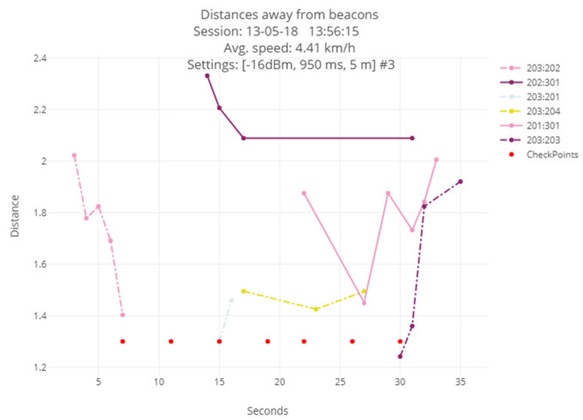
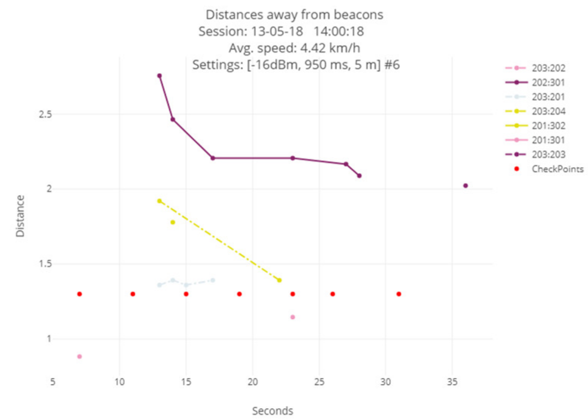
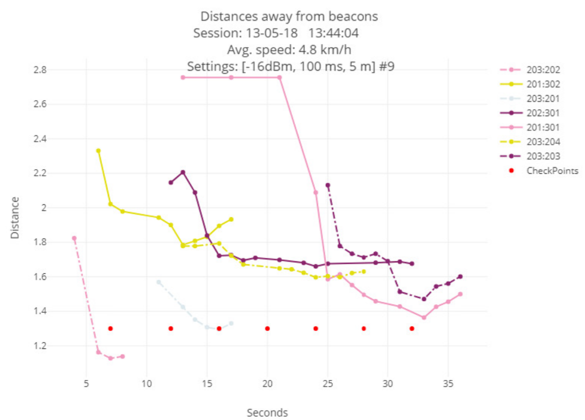
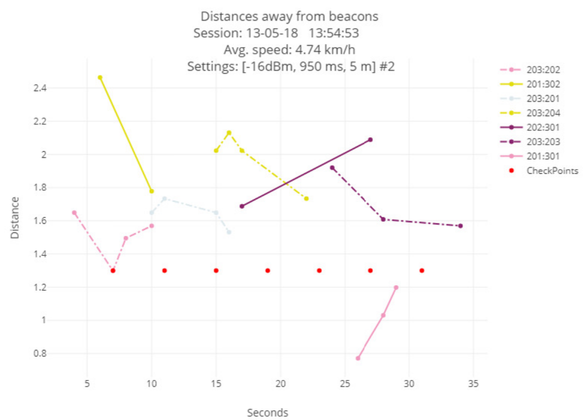
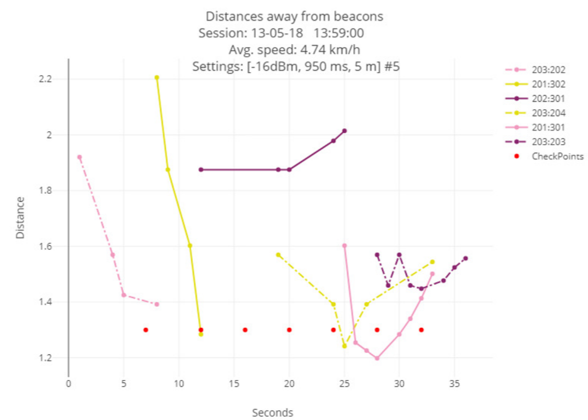
202:301
203:201
203:204
201:301
203:203
CheckPoints

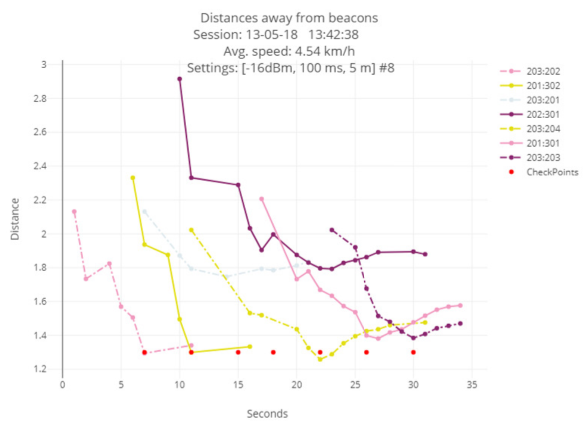

Distances away from beacons
Session: 13-05-18 13:56:15
Avg. speed: 4.41 km/h
Settings: [-16dBm, 950 ms, 5 m] #3
Distance
Seconds
203:202
202:301
203:201
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 14:00:18
Avg. speed: 4.42 km/h
Settings: [-16dBm, 950 ms, 5 m] #6
Distance
Seconds
203:202
202:301
203:201
203:204
201:302
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 13:44:04
Avg. speed: 4.8 km/h
Settings: [-16dBm, 100 ms, 5 m] #9
Distance
Seconds
203:202
201:302
203:201
202:301
201:301
203:204
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 13:54:53
Avg. speed: 4.74 km/h
Settings: [-16dBm, 950 ms, 5 m] #2
Distance
Seconds
203:202
201:302
203:201
203:204
202:301
203:203
201:301
CheckPoints


Distances away from beacons
Session: 13-05-18 13:59:00
Avg. speed: 4.74 km/h
Settings: [-16dBm, 950 ms, 5 m] #5
Distance
Seconds
203:202
201:302
202:301
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 13:42:38
Avg. speed: 4.54 km/h
Settings: [-16dBm, 100 ms, 5 m] #8
Distance
Seconds
203:202
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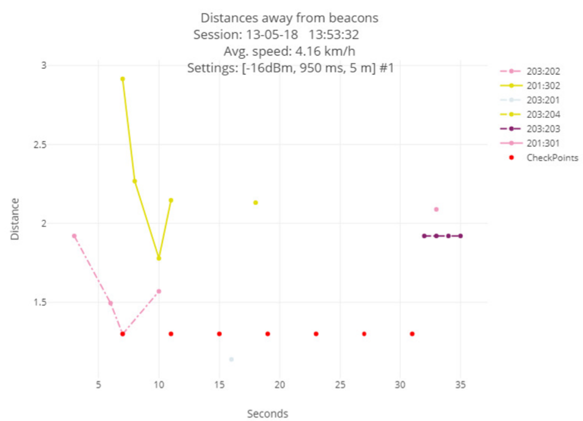
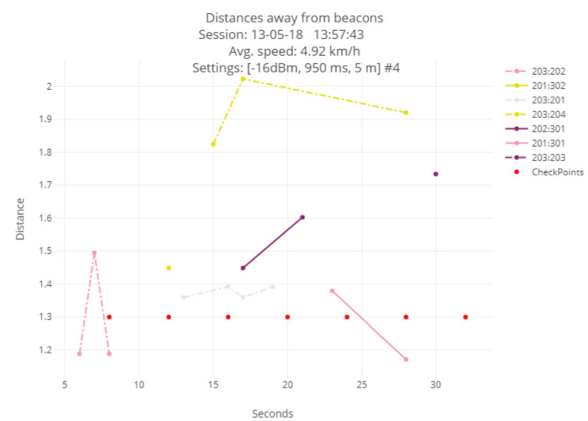
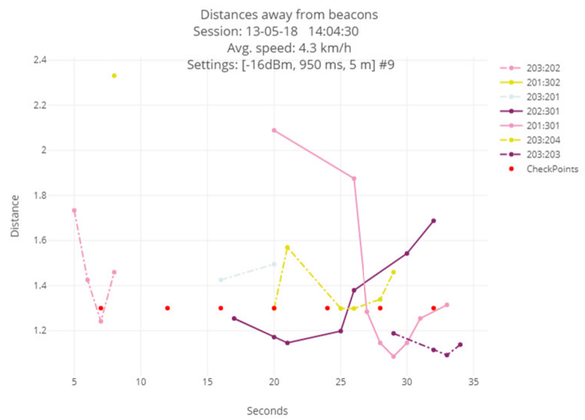
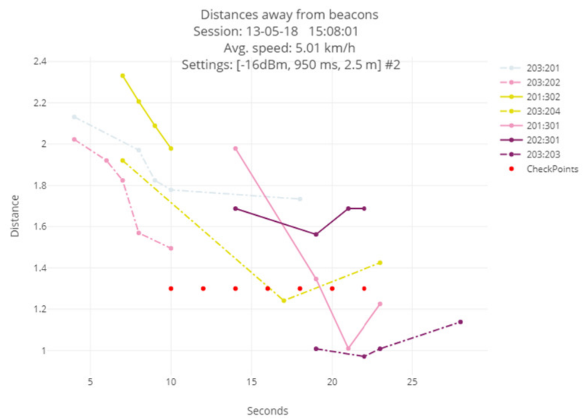
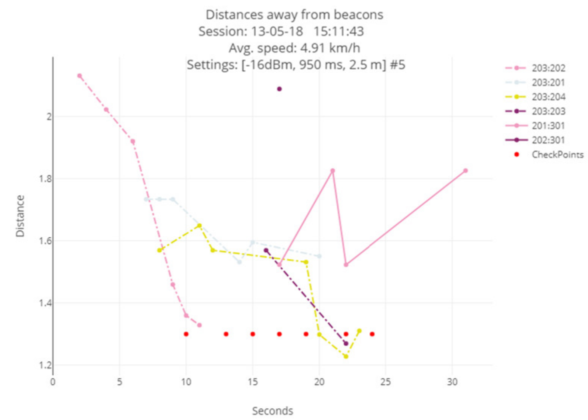
203:201
202:301
203:204
201:301
203:203
CheckPoints

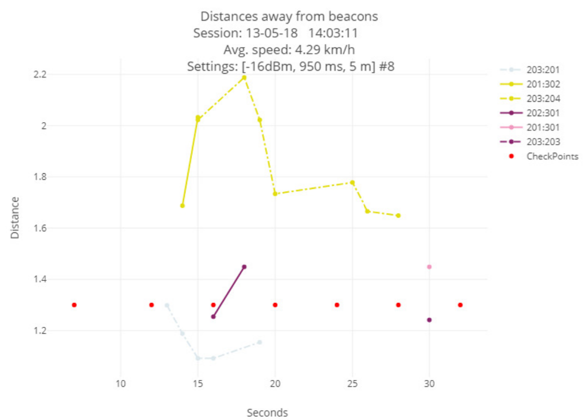

Distances away from beacons
Session: 13-05-18 13:53:32
Avg. speed: 4.16 km/h
Settings: [-16dBm, 950 ms, 5 m] #1
Distance
Seconds
203:202
201:302
203:201
203:204
203:203
201:301
CheckPoints

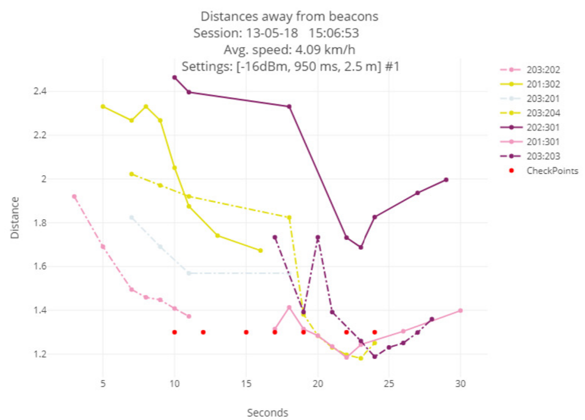

Distances away from beacons
Session: 13-05-18 13:57:43
Avg. speed: 4.92 km/h
Settings: [-16dBm, 950 ms, 5 m] #4
Distance
Seconds
203:202
201:302
203:201
203:204
202:301
201:301
203:203
CheckPoints

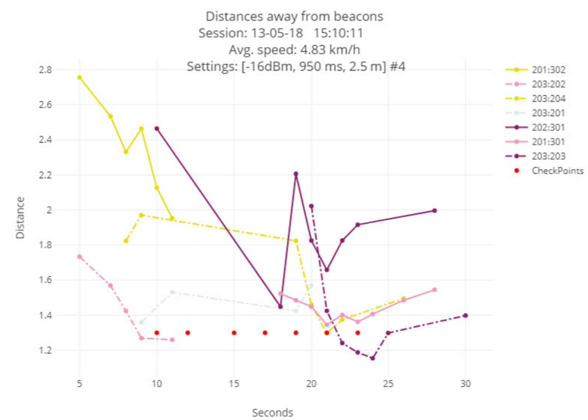

Distances away from beacons
Session: 13-05-18 14:04:30
Avg. speed: 4.3 km/h
Settings: [-16dBm, 950 ms, 5 m] #9
Distance
Seconds
203:202
201:302
203:201
202:301
201:301
203:204
203:203
CheckPoints

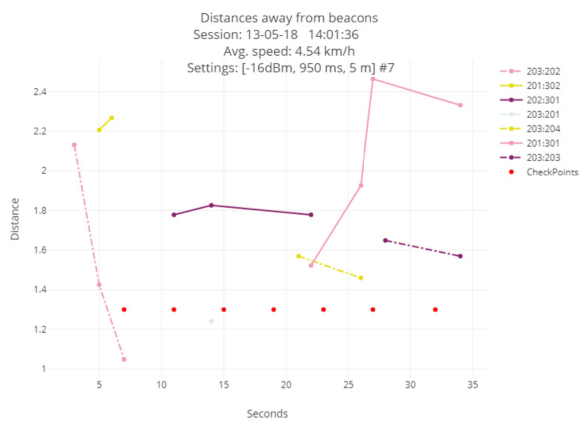

Distances away from beacons
Session: 13-05-18 15:08:01
Avg. speed: 5.01 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #2
Distance
Seconds
203:201
203:202
201:302
203:204
201:301
202:301
203:203
CheckPoints

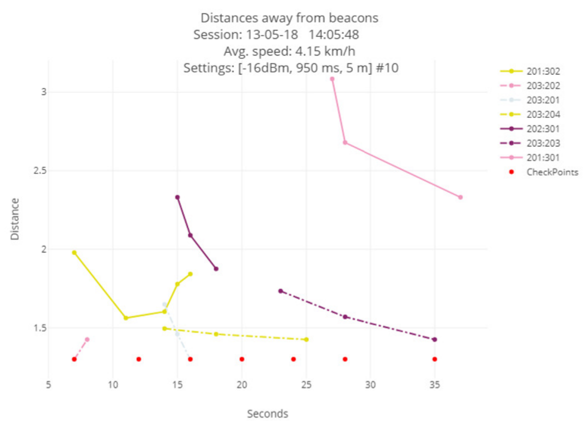

Distances away from beacons
Session: 13-05-18 15:11:43
Avg. speed: 4.91 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #5
Distance
Seconds
203:202
203:201
203:204
203:203
201:301
202:301
CheckPoints

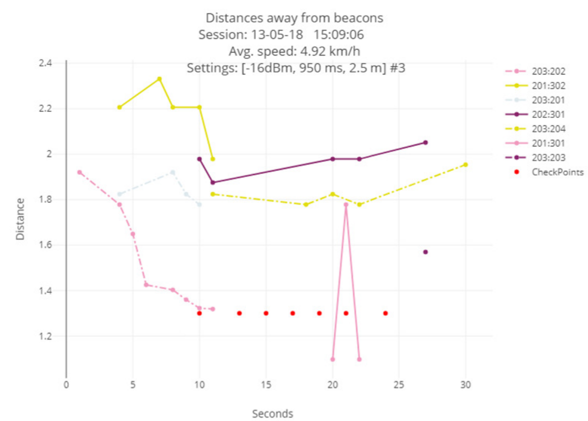

Distances away from beacons
Session: 13-05-18 14:03:11
Avg. speed: 4.29 km/h
Settings: [-16dBm, 950 ms, 5 m] #8
Distance
Seconds
203:201
201:302
203:204
202:301
201:301
203:203
CheckPoints

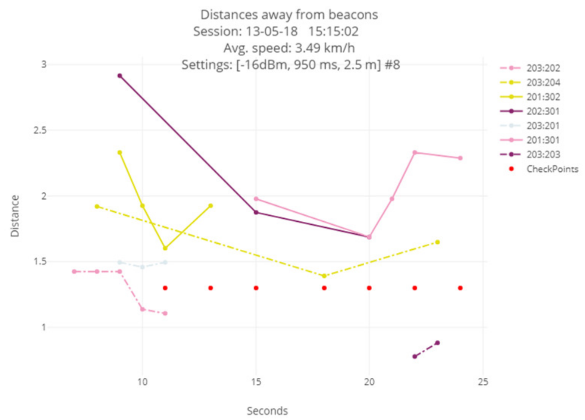

Distances away from beacons
Session: 13-05-18 15:06:53
Avg. speed: 4.09 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #1
Distance
Seconds
203:202
201:302
203:201
203:204
202:301
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 15:10:11
Avg. speed: 4.83 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #4
Distance
Seconds
201:302
203:202
203:204
203:201
202:301
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 14:01:36
Avg. speed: 4.54 km/h
Settings: [-16dBm, 950 ms, 5 m] #7
Distance
Seconds
203:202
201:302
202:301
203:201
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 14:05:48
Avg. speed: 4.15 km/h
Settings: [-16dBm, 950 ms, 5 m] #10
Distance
Seconds
201:302
203:202
203:201
203:204
202:301
203:203
201:301
CheckPoints


Distances away from beacons
Session: 13-05-18 15:09:06
Avg. speed: 4.92 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #3
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 15:15:02
Avg. speed: 3.49 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #8
Distance
Seconds
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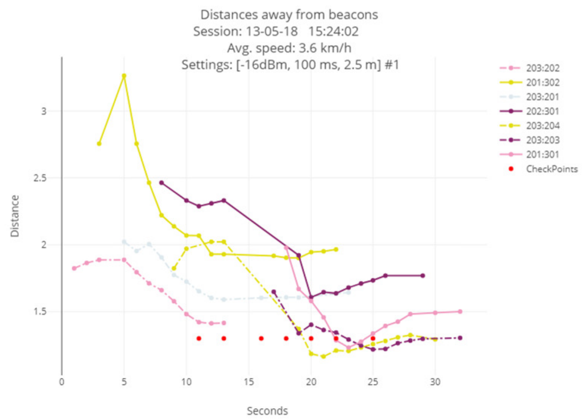
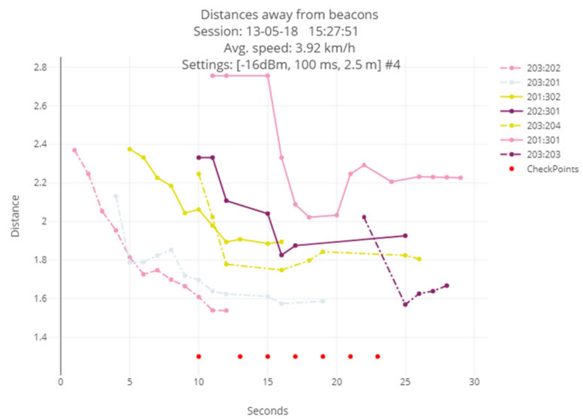
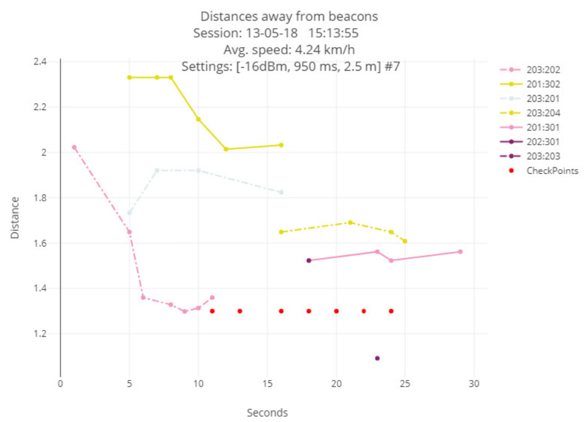
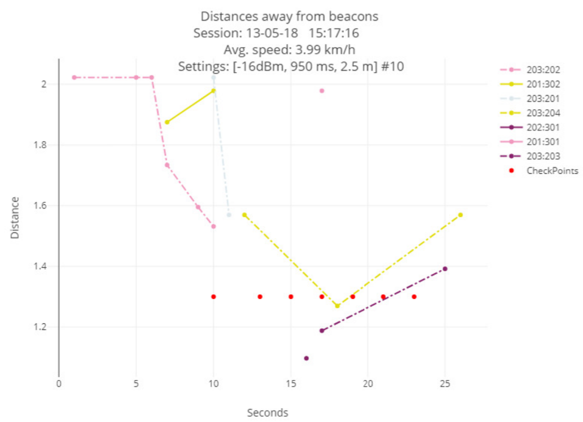
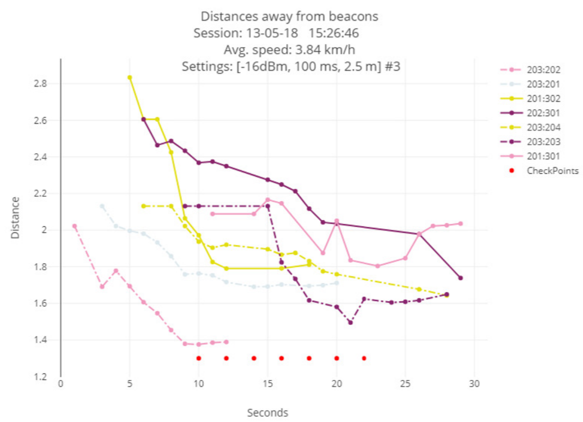
203:204
201:302
202:301
203:201
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 15:24:02
Avg. speed: 3.6 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #1
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
203:203
201:301
CheckPoints


Distances away from beacons
Session: 13-05-18 15:27:51
Avg. speed: 3.92 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #4
Distance
Seconds
203:202
203:201
201:302
202:301
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 15:13:55
Avg. speed: 4.24 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #7
Distance
Seconds
203:202
201:302
203:201
203:204
201:301
202:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 15:17:16
Avg. speed: 3.99 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #10
Distance
Seconds
203:202
201:302
203:201
203:204
202:301
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 15:26:46
Avg. speed: 3.84 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #3
Distance
Seconds
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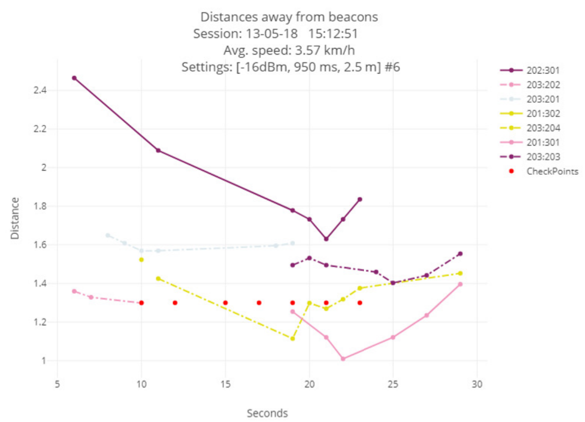
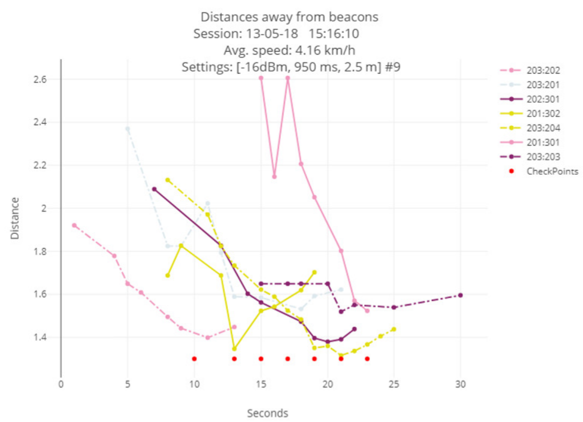
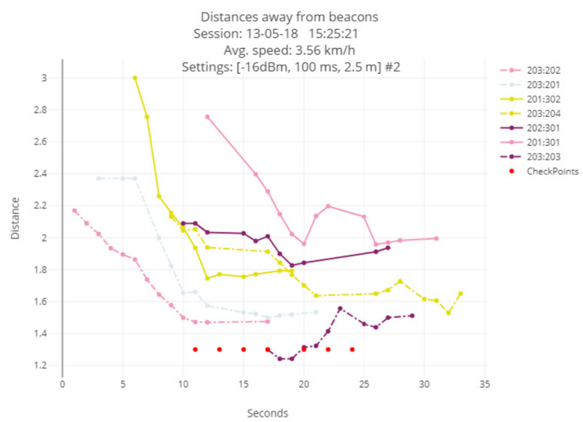
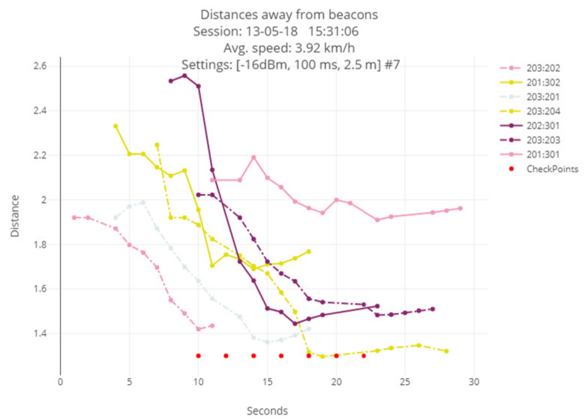
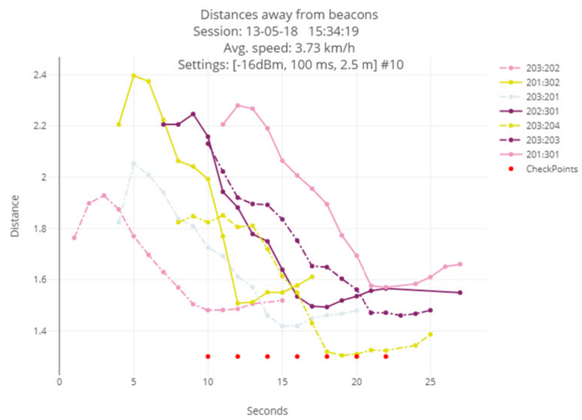
203:201
201:302
202:301
203:204
203:203
201:301
CheckPoints

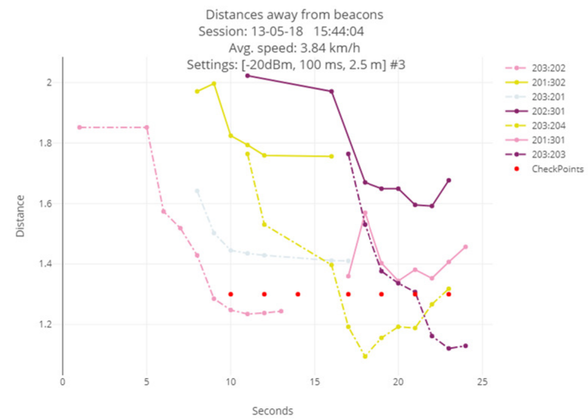

Distances away from beacons
Session: 13-05-18 15:12:51
Avg. speed: 3.57 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #6
Distance
Seconds
202:301
203:202
203:201
201:302
203:204
201:301
203:203
CheckPoints

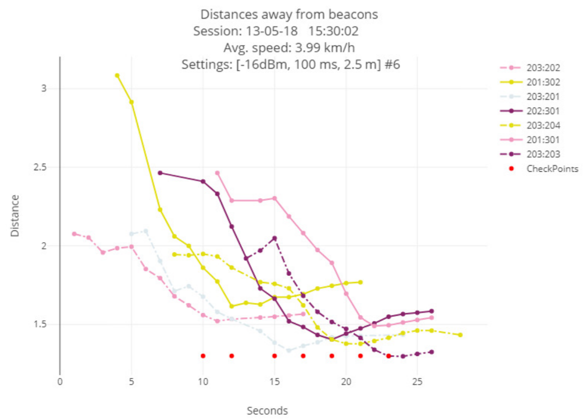

Distances away from beacons
Session: 13-05-18 15:16:10
Avg. speed: 4.16 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #9
Distance
Seconds
203:202
203:201
202:301
201:302
203:204
201:301
203:203
CheckPoints

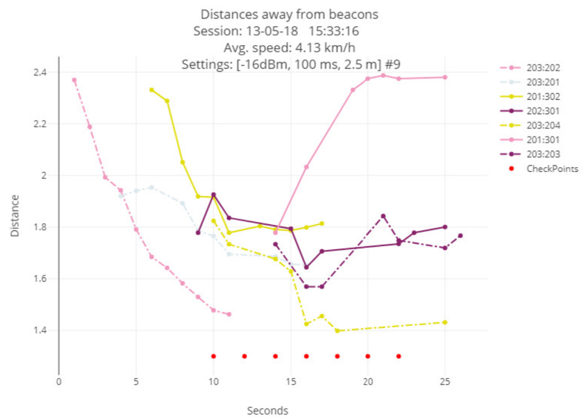

Distances away from beacons
Session: 13-05-18 15:25:21
Avg. speed: 3.56 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #2
Distance
Seconds
203:202
203:201
201:302
203:204
202:301
201:301
203:203
CheckPoints

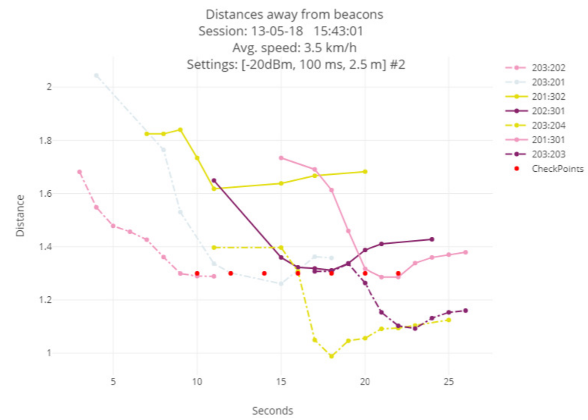

Distances away from beacons
Session: 13-05-18 15:31:06
Avg. speed: 3.92 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #7
Distance
Seconds
203:202
201:302
203:201
203:204
202:301
203:203
201:301
CheckPoints

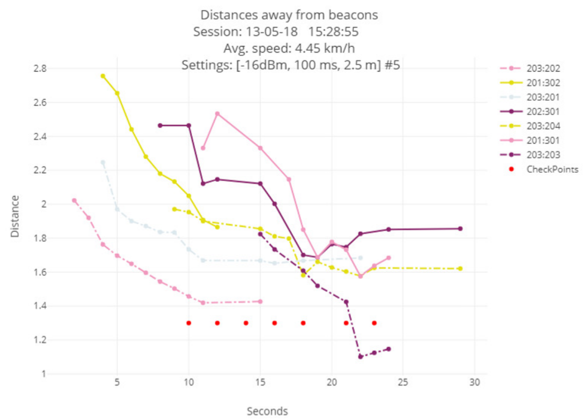

Distances away from beacons
Session: 13-05-18 15:34:19
Avg. speed: 3.73 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #10
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
203:203
201:301
CheckPoints

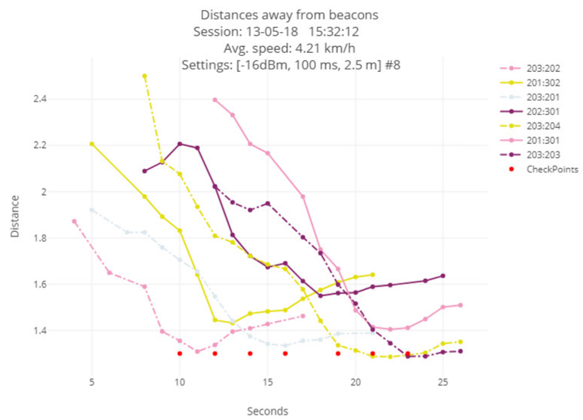

Distances away from beacons
Session: 13-05-18 15:44:04
Avg. speed: 3.84 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #3
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 15:30:02
Avg. speed: 3.99 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #6
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints

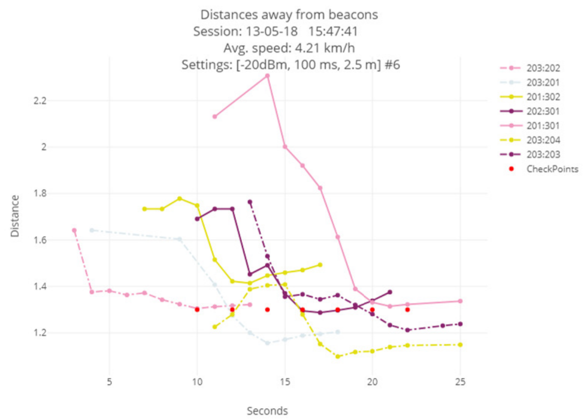

Distances away from beacons
Session: 13-05-18 15:33:16
Avg. speed: 4.13 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #9
Distance
Seconds
203:202
203:201
201:302
202:301
203:204
201:301
203:203
CheckPoints

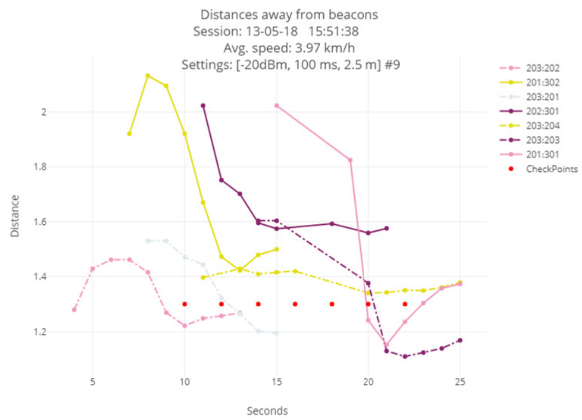

Distances away from beacons
Session: 13-05-18 15:43:01
Avg. speed: 3.5 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #2
Distance
Seconds
203:202
203:201
201:302
202:301
203:204
201:301
203:203
CheckPoints

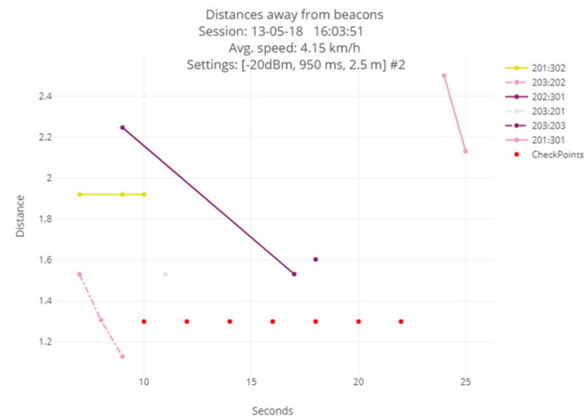

Distances away from beacons
Session: 13-05-18 15:28:55
Avg. speed: 4.45 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #5
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints

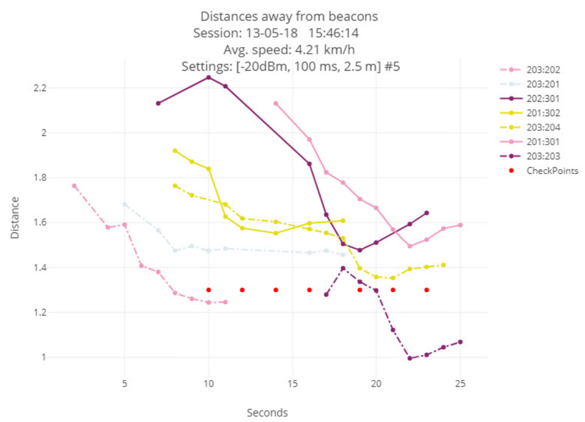

Distances away from beacons
Session: 13-05-18 15:32:12
Avg. speed: 4.21 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #8
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 15:41:54
Avg. speed: 3.3 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #1
Distance
Seconds
203:202
203:201
201:302
202:301
201:301
203:203
203:204
CheckPoints


Distances away from beacons
Session: 13-05-18 15:47:41
Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #6
Distance
Seconds
203:202
203:201
201:302
202:301
201:301
203:204
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 15:51:38
Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #9
Distance
Seconds
203:202
201:302
203:201
202:301
203:204
203:203
201:301
CheckPoints


Distances away from beacons
Session: 13-05-18 16:03:51
Avg. speed: 4.15 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #2
Distance
Seconds
201:302
203:202
202:301
203:201
203:203
201:301
CheckPoints


Distances away from beacons
Session: 13-05-18 15:46:14
Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #5
Distance
Seconds
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203:201
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201:302
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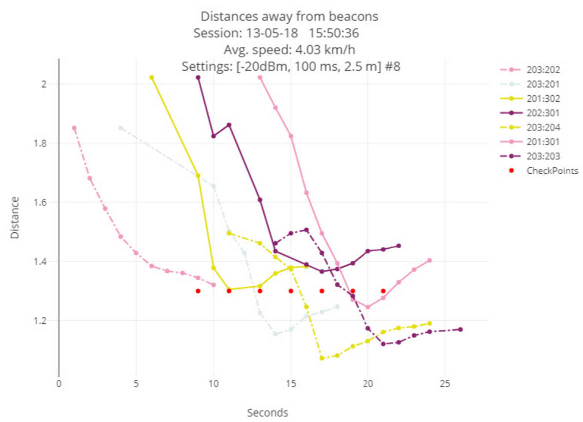
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 15:50:36
Avg. speed: 4.03 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #8
Distance
Seconds
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203:201
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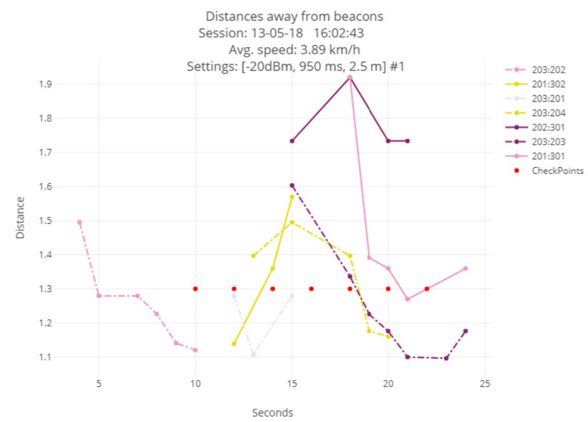
202:301
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 16:02:43
Avg. speed: 3.89 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #1
Distance
Seconds
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201:302
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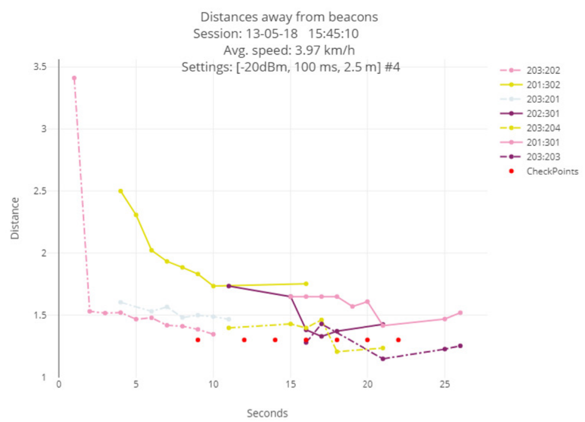
203:204
202:301
203:203
201:301
CheckPoints


Distances away from beacons
Session: 13-05-18 15:45:10
Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #4
Distance
Seconds
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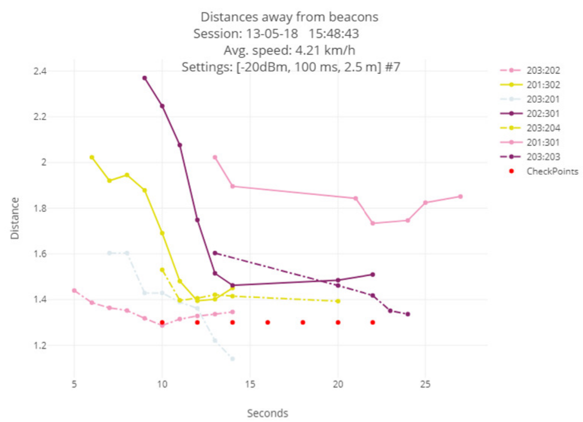
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 15:48:43
Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #7
Distance
Seconds
203:202
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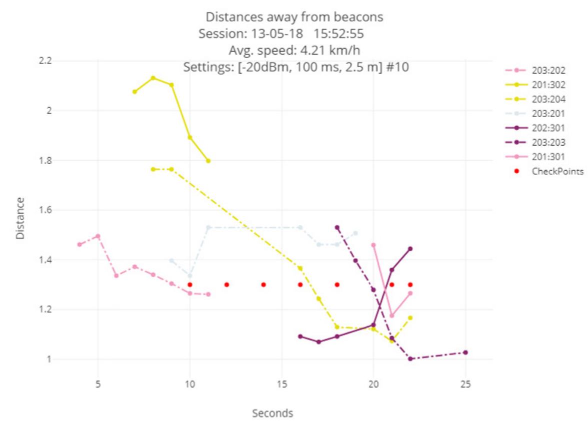
202:301
203:204
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 15:52:55
Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #10
Distance
Seconds
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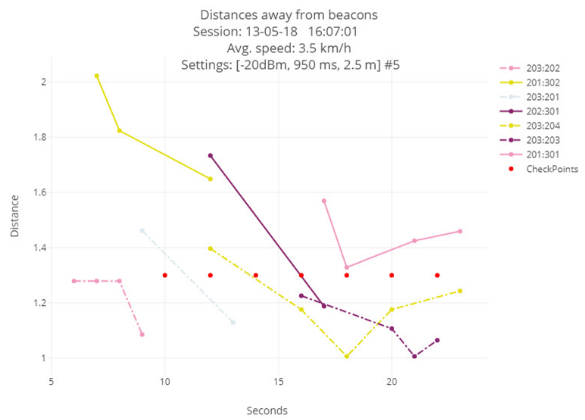
203:204
203:201
202:301
203:203
201:301
CheckPoints


Distances away from beacons
Session: 13-05-18 16:07:01
Avg. speed: 3.5 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #5
Distance
Seconds
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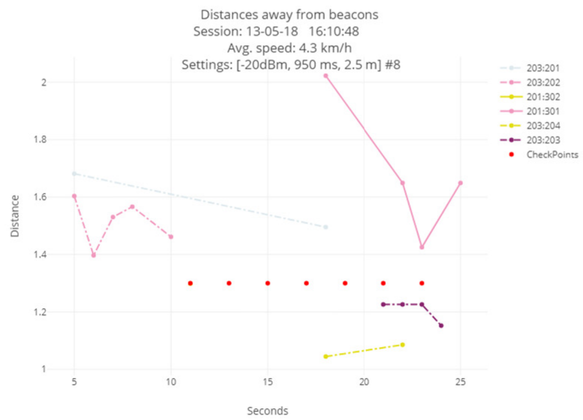
202:301
203:204
203:203
201:301
CheckPoints


Distances away from beacons
Session: 13-05-18 16:10:48
Avg. speed: 4.3 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #8
Distance
Seconds
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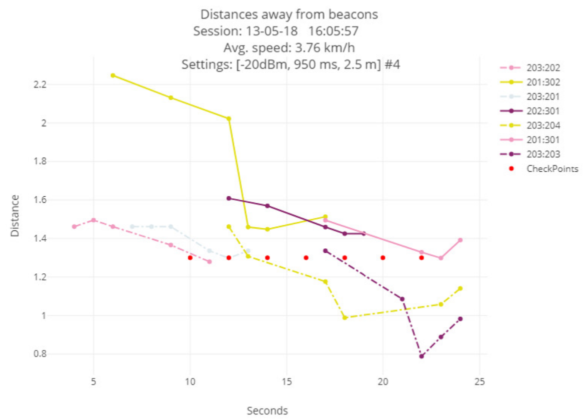
203:202
201:302
201:301
203:204
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 16:05:57
Avg. speed: 3.76 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #4
Distance
Seconds
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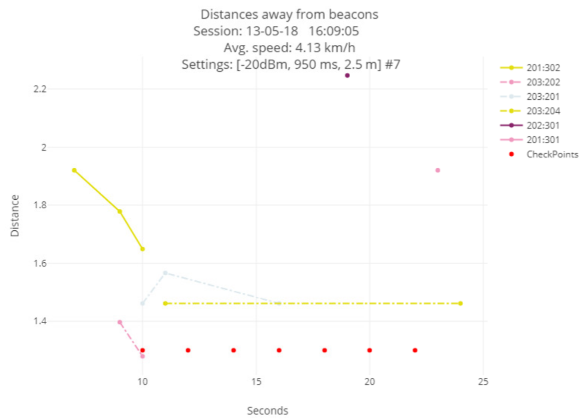
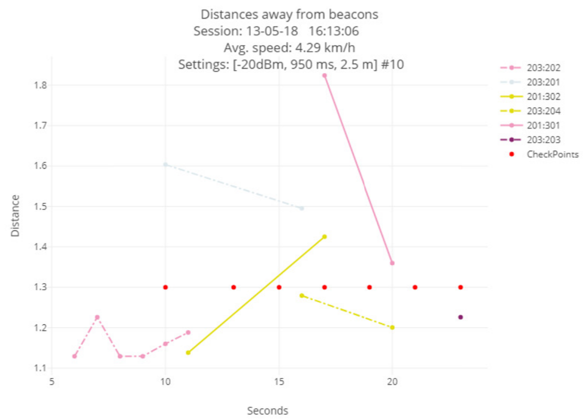
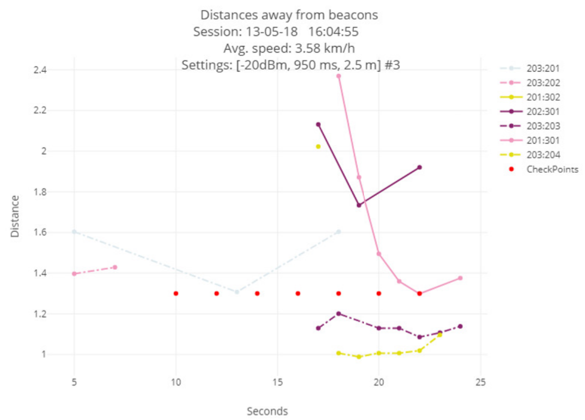
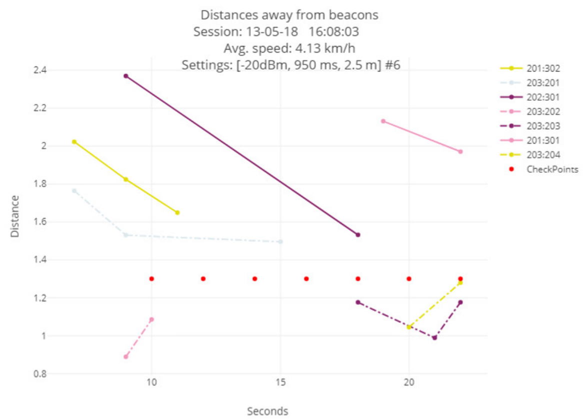
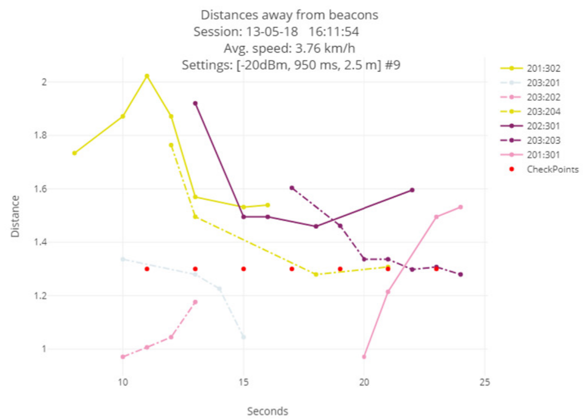
201:301
203:203
CheckPoints


Distances away from beacons
Session: 13-05-18 16:09:05
Avg. speed: 4.13 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #7
Distance
Seconds
201:302
203:202
203:201
203:204
202:301
201:301
CheckPoints


Distances away from beacons
Session: 13-05-18 16:13:06
Avg. speed: 4.29 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #10
Distance
Seconds
203:202
203:201
201:302
203:204
201:301
203:203
CheckPoints

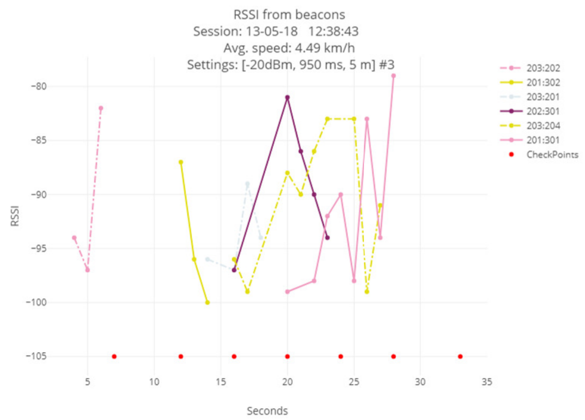

Distances away from beacons
Session: 13-05-18 16:04:55
Avg. speed: 3.58 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #3
Distance
Seconds
203:201
203:202
201:302
202:301
203:203
201:301
203:204
CheckPoints

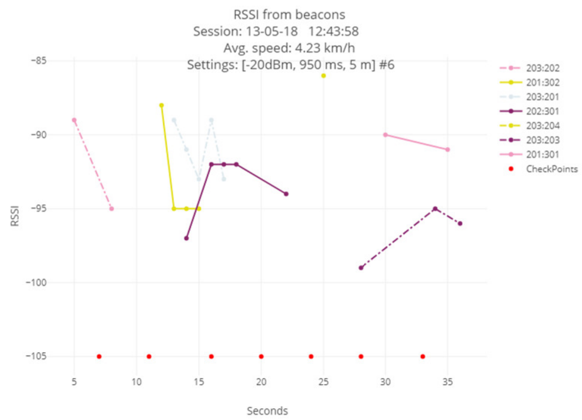

Distances away from beacons
Session: 13-05-18 16:08:03
Avg. speed: 4.13 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #6
Distance
Seconds
201:302
203:201
202:301
203:202
203:203
201:301
203:204
CheckPoints

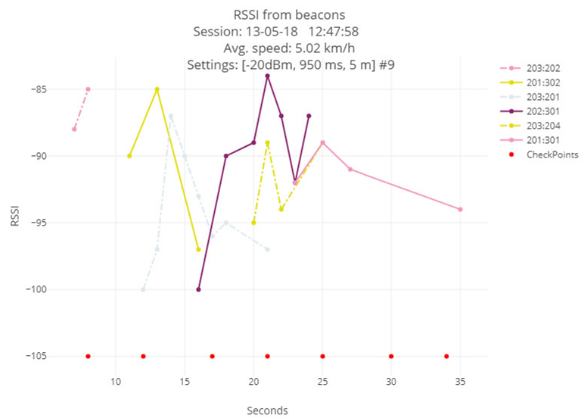

Distances away from beacons
Session: 13-05-18 16:11:54
Avg. speed: 3.76 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #9
Distance
Seconds
201:302
203:201
203:202
203:204
202:301
203:203
201:301
CheckPoints

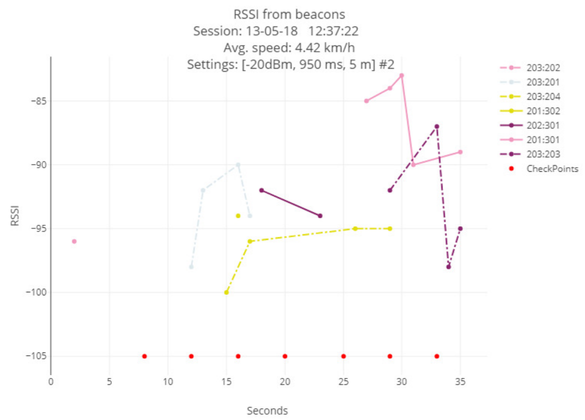
11.1.2 RSSI graphs

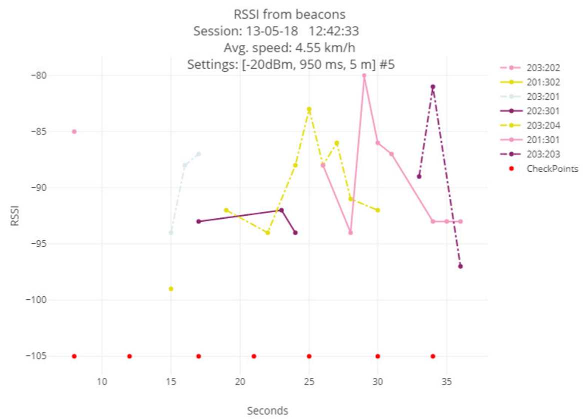
The attachment is on the next page(s).


RSSI from beacons
Session: 13-05-18 12:38:43
Avg. speed: 4.49 km/h
Settings: [-20dBm, 950 ms, 5 m] #3
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
CheckPoints


RSSI from beacons
Session: 13-05-18 12:43:58
Avg. speed: 4.23 km/h
Settings: [-20dBm, 950 ms, 5 m] #6
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
203:203
201:301
CheckPoints


RSSI from beacons
Session: 13-05-18 12:47:58
Avg. speed: 5.02 km/h
Settings: [-20dBm, 950 ms, 5 m] #9
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
CheckPoints


RSSI from beacons
Session: 13-05-18 12:37:22
Avg. speed: 4.42 km/h
Settings: [-20dBm, 950 ms, 5 m] #2
RSSI
Seconds
203:202
203:201
203:204
201:302
202:301
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 12:42:33
Avg. speed: 4.55 km/h
Settings: [-20dBm, 950 ms, 5 m] #5
RSSI
Seconds
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201:302
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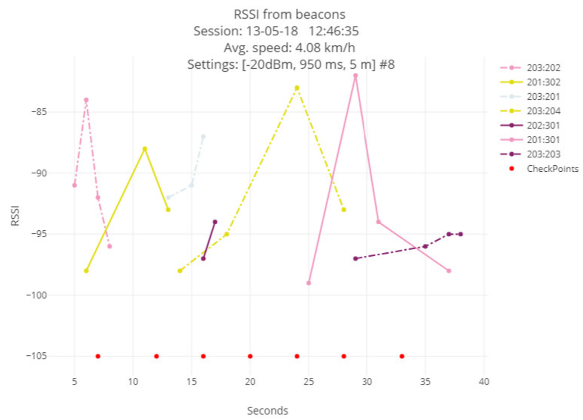
202:301
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 12:46:35
Avg. speed: 4.08 km/h
Settings: [-20dBm, 950 ms, 5 m] #8
RSSI
Seconds
203:202
201:302
203:201
203:204
202:301
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 12:36:04
Avg. speed: 3.88 km/h
Settings: [-20dBm, 950 ms, 5 m] #1
RSSI
Seconds
203:202
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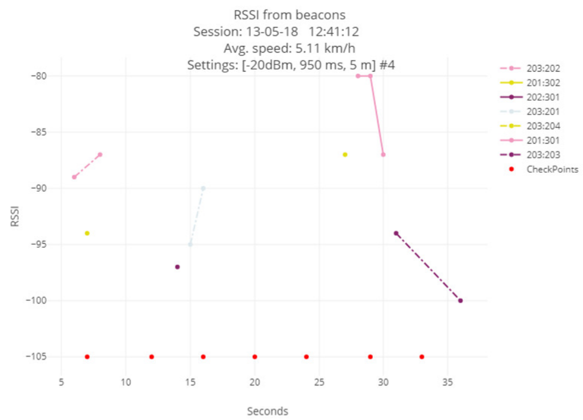
202:301
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 12:41:12
Avg. speed: 5.11 km/h
Settings: [-20dBm, 950 ms, 5 m] #4
RSSI
Seconds
203:202
201:302
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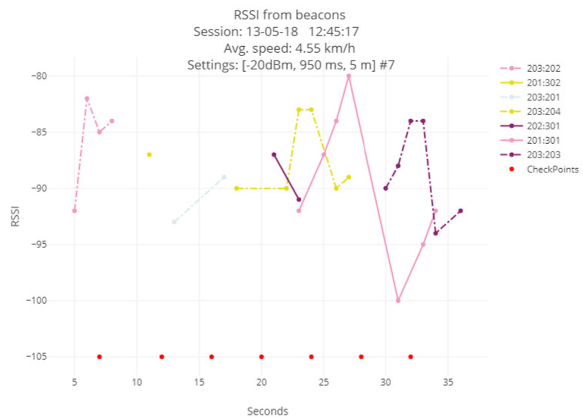
203:201
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 12:45:17
Avg. speed: 4.55 km/h
Settings: [-20dBm, 950 ms, 5 m] #7
RSSI
Seconds
203:202
201:302
203:201
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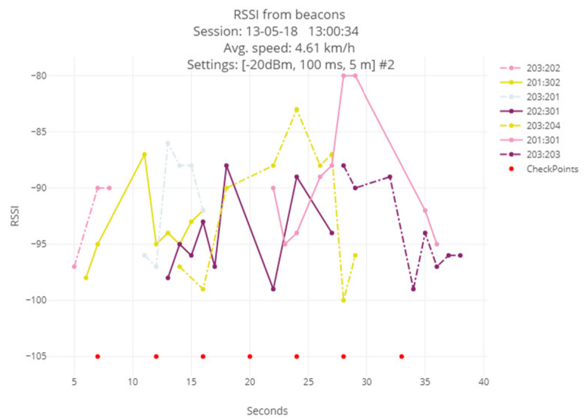
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:00:34
Avg. speed: 4.61 km/h
Settings: [-20dBm, 100 ms, 5 m] #2
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:05:36
Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 5 m] #5
RSSI
Seconds
203:202
201:302
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202:301
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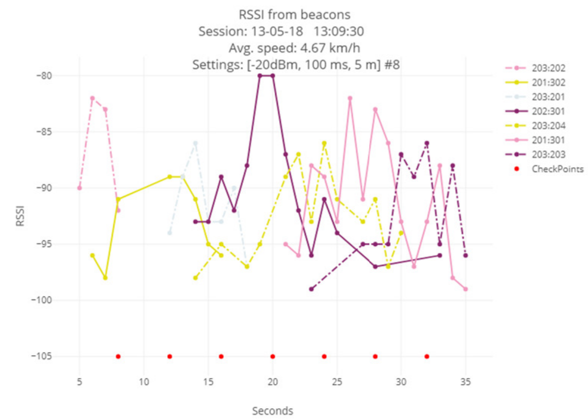
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:09:30
Avg. speed: 4.67 km/h
Settings: [-20dBm, 100 ms, 5 m] #8
RSSI
Seconds
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202:301
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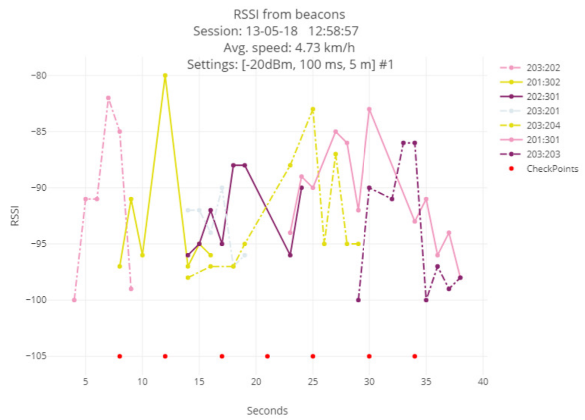
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 12:58:57
Avg. speed: 4.73 km/h
Settings: [-20dBm, 100 ms, 5 m] #1
RSSI
Seconds
203:202
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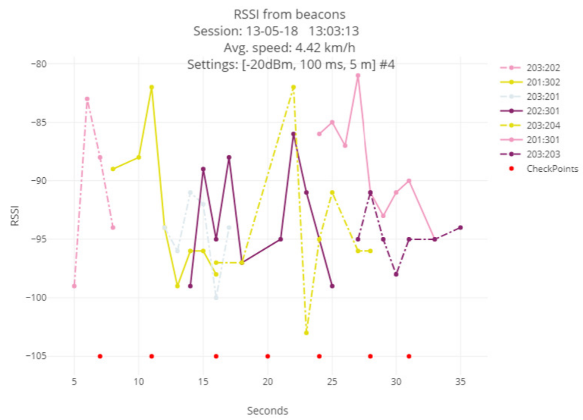
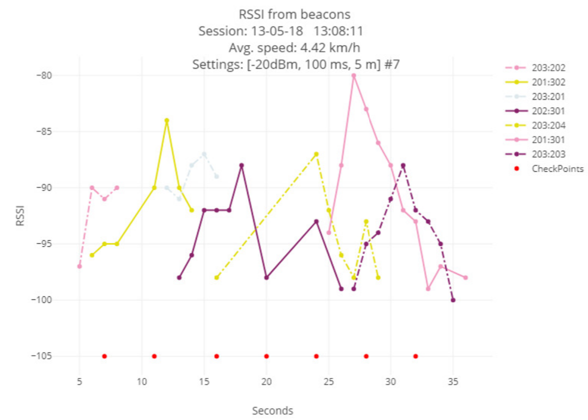
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:03:13
Avg. speed: 4.42 km/h
Settings: [-20dBm, 100 ms, 5 m] #4
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:08:11
Avg. speed: 4.42 km/h
Settings: [-20dBm, 100 ms, 5 m] #7
RSSI
Seconds
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202:301
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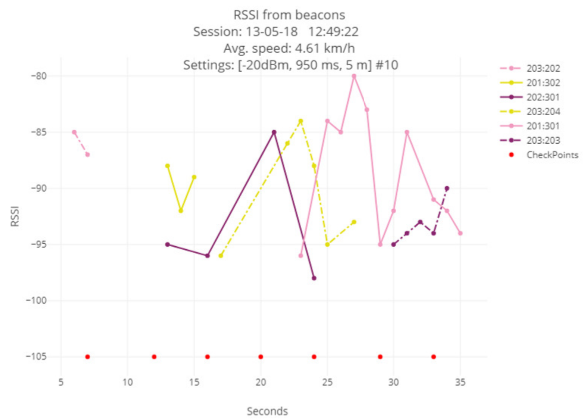
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 12:49:22
Avg. speed: 4.61 km/h
Settings: [-20dBm, 950 ms, 5 m] #10
RSSI
Seconds
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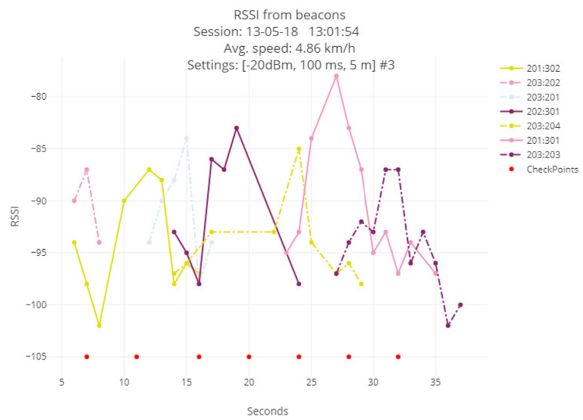
202:301
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:01:54
Avg. speed: 4.86 km/h
Settings: [-20dBm, 100 ms, 5 m] #3
RSSI
Seconds
201:302
203:202
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202:301
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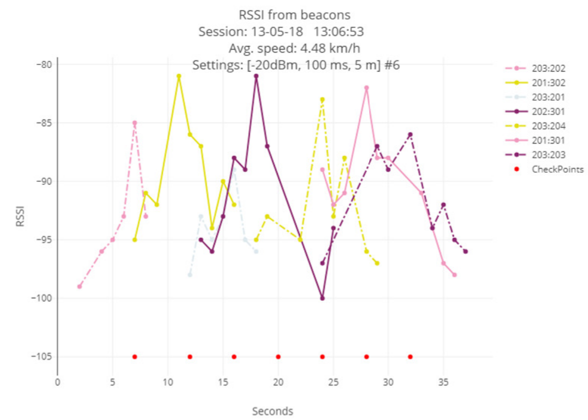
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:06:53
Avg. speed: 4.48 km/h
Settings: [-20dBm, 100 ms, 5 m] #6
RSSI
Seconds
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201:302
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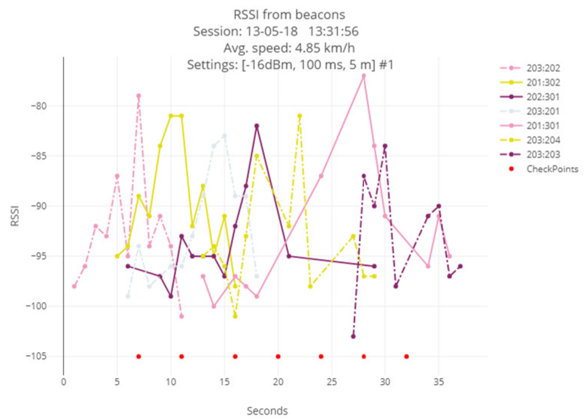
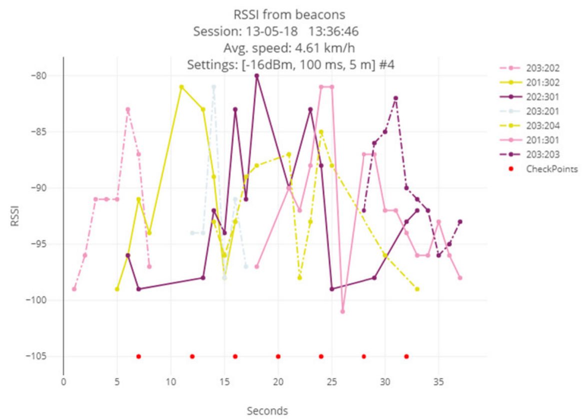
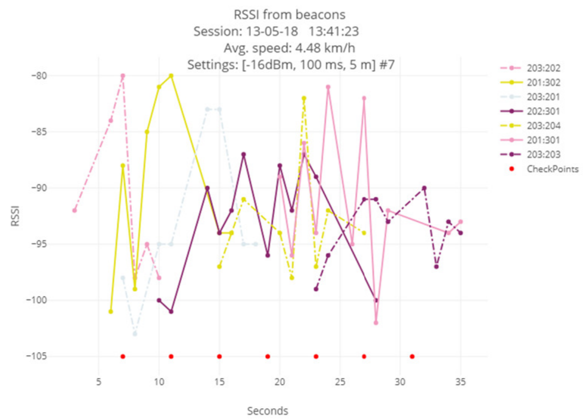
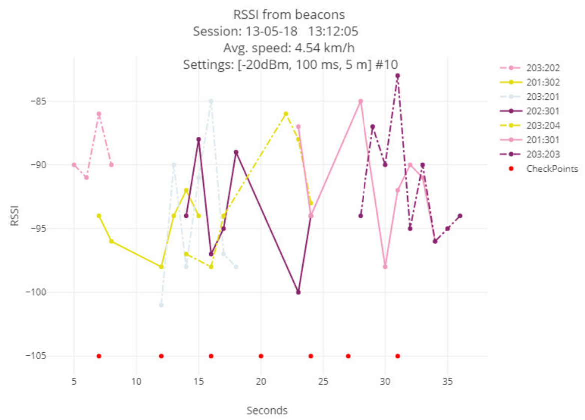
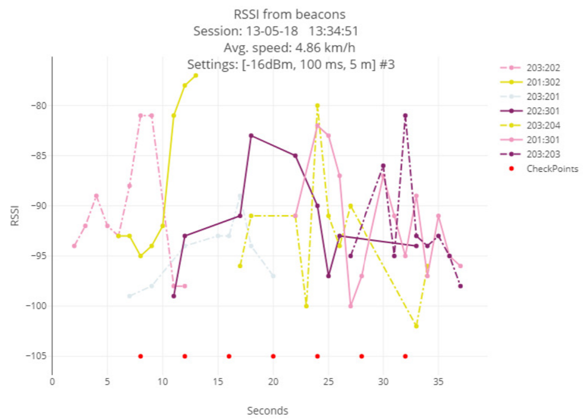
202:301
203:204
201:301
203:203
CheckPoints

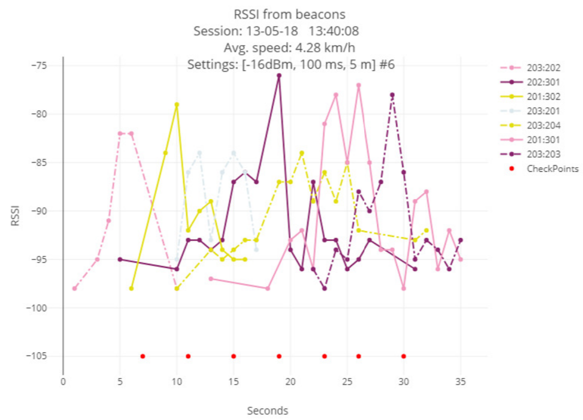

RSSI from beacons
Session: 13-05-18 13:31:56
Avg. speed: 4.85 km/h
Settings: [-16dBm, 100 ms, 5 m] #1
RSSI
Seconds
203:202
201:302
202:301
203:201
201:301
203:204
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:36:46
Avg. speed: 4.61 km/h
Settings: [-16dBm, 100 ms, 5 m] #4
RSSI
Seconds
203:202
201:302
202:301
203:201
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:41:23
Avg. speed: 4.48 km/h
Settings: [-16dBm, 100 ms, 5 m] #7
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:12:05
Avg. speed: 4.54 km/h
Settings: [-20dBm, 100 ms, 5 m] #10
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:34:51
Avg. speed: 4.86 km/h
Settings: [-16dBm, 100 ms, 5 m] #3
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:40:08
Avg. speed: 4.28 km/h
Settings: [-16dBm, 100 ms, 5 m] #6
RSSI
Seconds
203:202
202:301
201:302
203:201
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:10:48
Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 5 m] #9
RSSI
Seconds
203:202
201:302
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202:301
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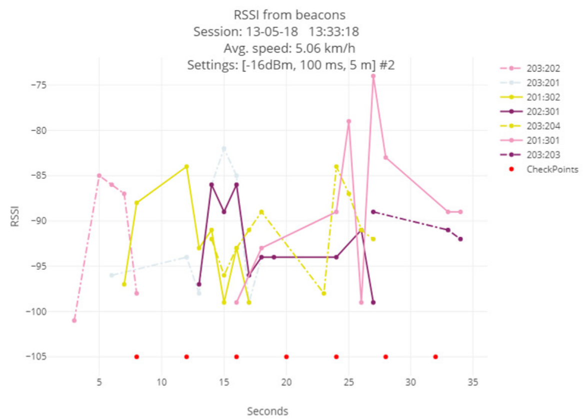
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:33:18
Avg. speed: 5.06 km/h
Settings: [-16dBm, 100 ms, 5 m] #2
RSSI
Seconds
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203:201
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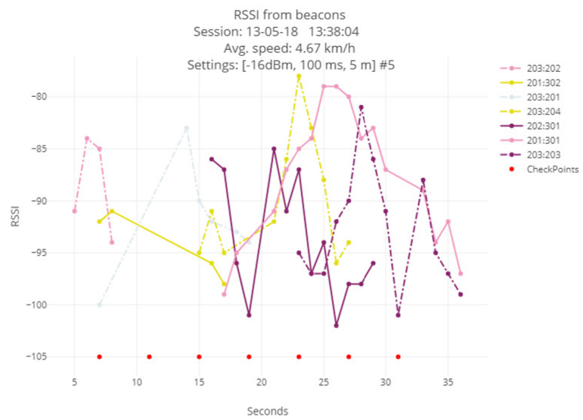
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 13:38:04
Avg. speed: 4.67 km/h
Settings: [-16dBm, 100 ms, 5 m] #5
RSSI
Seconds
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201:302
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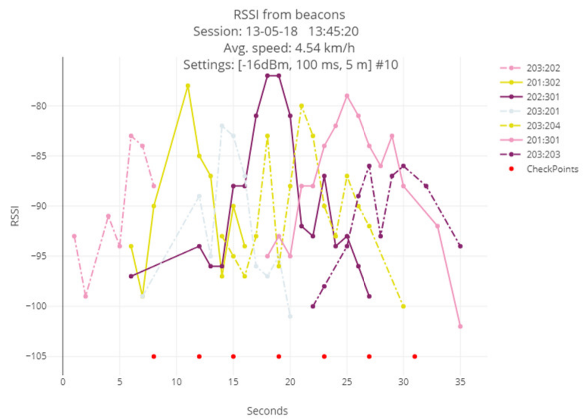
CheckPoints


RSSI from beacons
Session: 13-05-18 13:45:20
Avg. speed: 4.54 km/h
Settings: [-16dBm, 100 ms, 5 m] #10
203:202
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202:301
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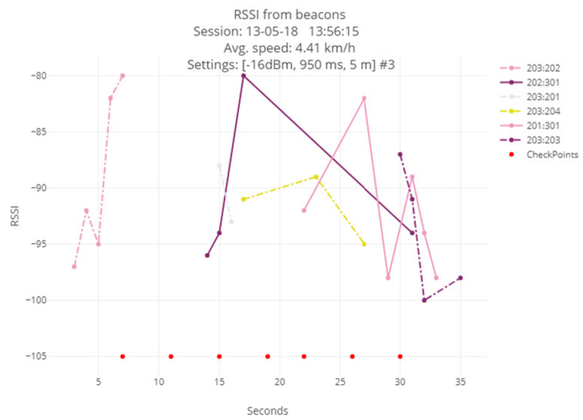
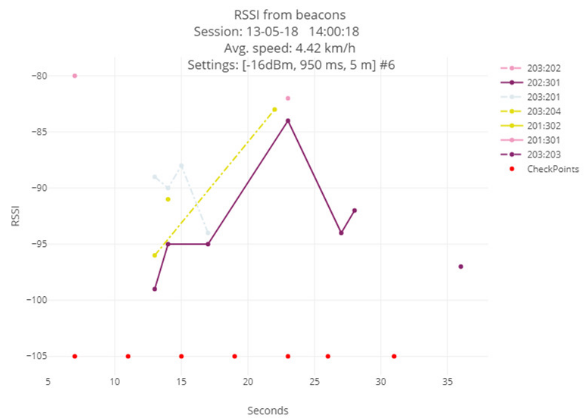
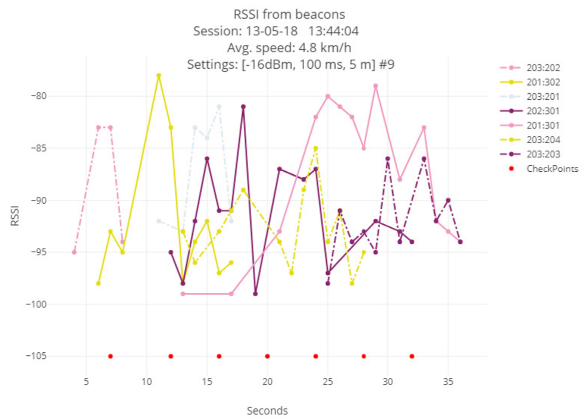
201:301
203:203
CheckPoints
RSSI
Seconds


RSSI from beacons
Session: 13-05-18 13:56:15
Avg. speed: 4.41 km/h
Settings: [-16dBm, 950 ms, 5 m] #3
203:202
202:301
203:201
203:204
201:301
203:203
CheckPoints
RSSI
Seconds


RSSI from beacons
Session: 13-05-18 14:00:18
Avg. speed: 4.42 km/h
Settings: [-16dBm, 950 ms, 5 m] #6
203:202
202:301
203:201
203:204
201:302
201:301
203:203
CheckPoints
RSSI
Seconds


RSSI from beacons
Session: 13-05-18 13:44:04
Avg. speed: 4.8 km/h
Settings: [-16dBm, 100 ms, 5 m] #9
203:202
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201:301
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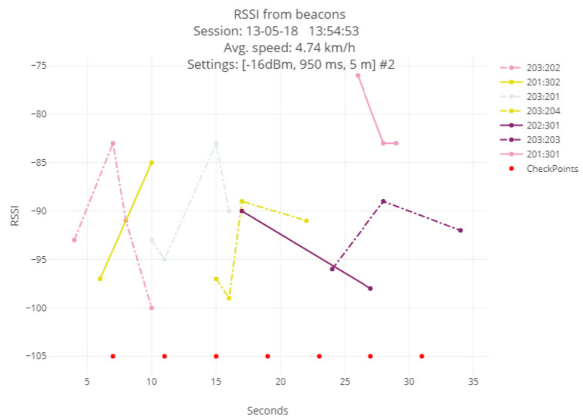
203:203
CheckPoints
RSSI
Seconds


RSSI from beacons
Session: 13-05-18 13:54:53
Avg. speed: 4.74 km/h
Settings: [-16dBm, 950 ms, 5 m] #2
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202:301
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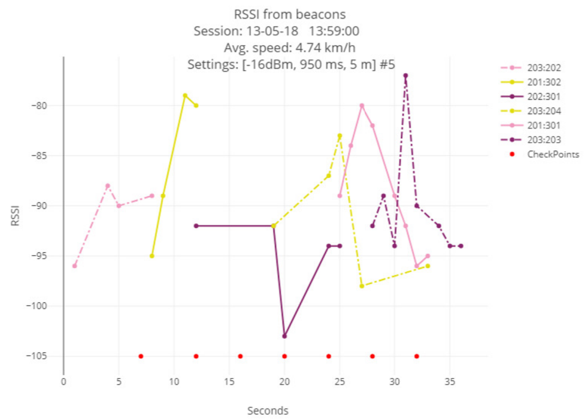
201:301
CheckPoints
RSSI
Seconds


RSSI from beacons
Session: 13-05-18 13:59:00
Avg. speed: 4.74 km/h
Settings: [-16dBm, 950 ms, 5 m] #5
203:202
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202:301
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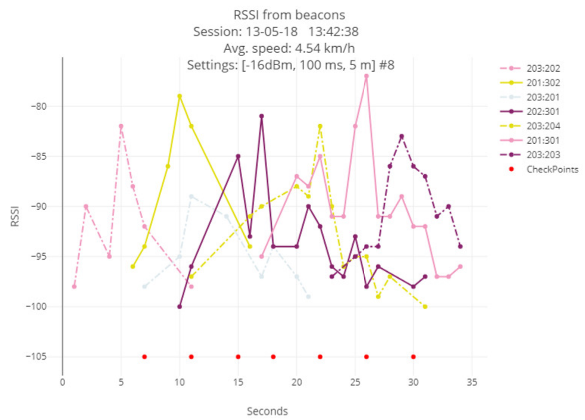
201:301
203:203
CheckPoints
RSSI
Seconds


RSSI from beacons
Session: 13-05-18 13:42:38
Avg. speed: 4.54 km/h
Settings: [-16dBm, 100 ms, 5 m] #8
203:202
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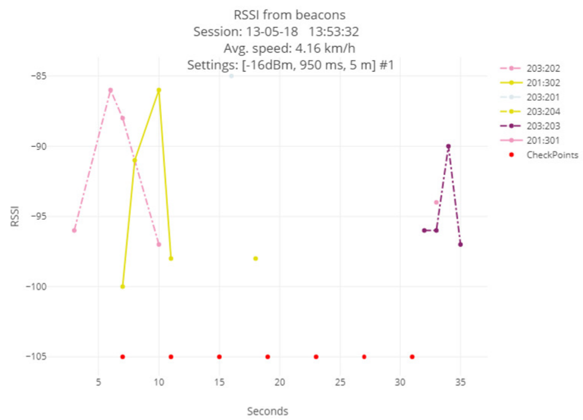
203:204
201:301
203:203
CheckPoints
RSSI
Seconds


RSSI from beacons
Session: 13-05-18 13:53:32
Avg. speed: 4.16 km/h
Settings: [-16dBm, 950 ms, 5 m] #1
203:202
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203:201
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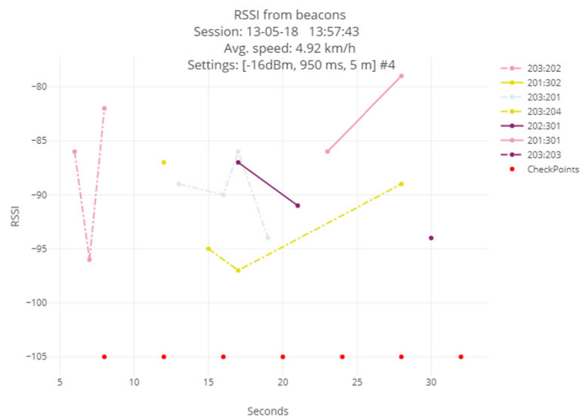
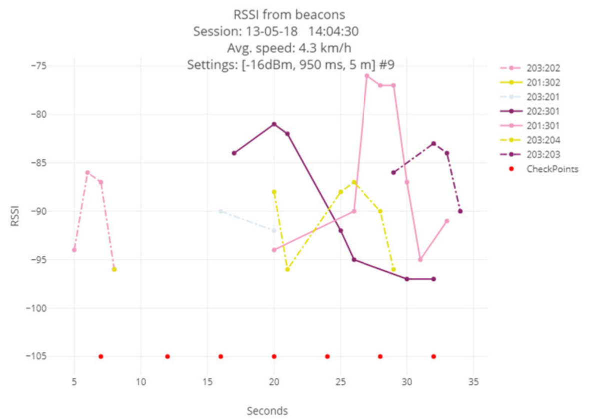
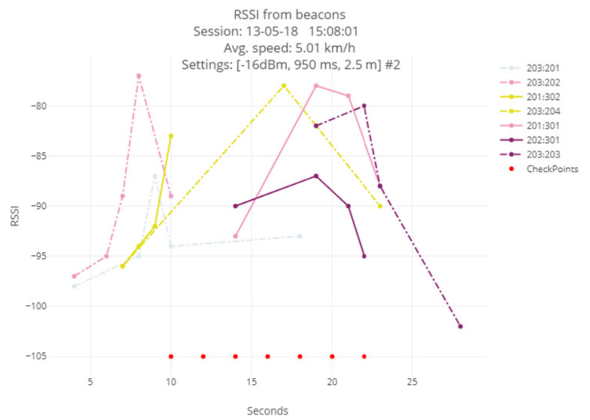
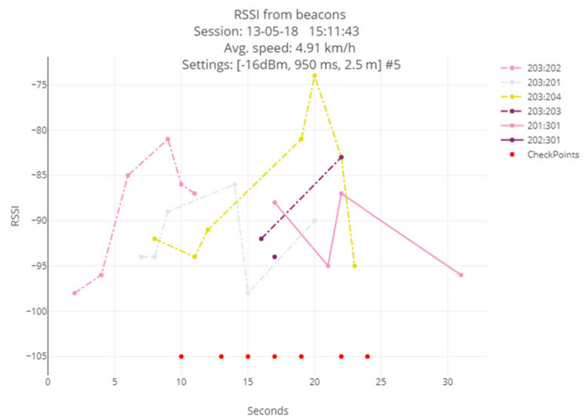
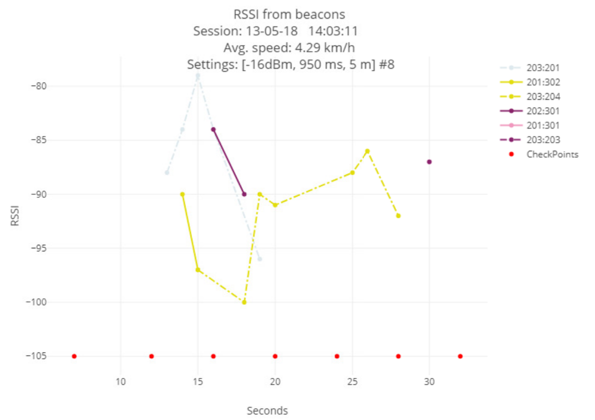
203:203
201:301
CheckPoints
RSSI
Seconds

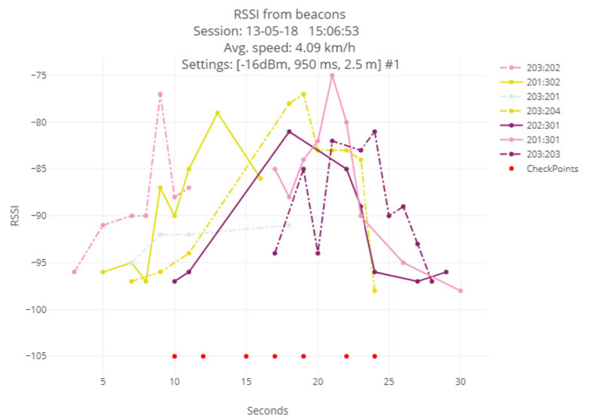

RSSI from beacons
Session: 13-05-18 13:57:43
Avg. speed: 4.92 km/h
Settings: [-16dBm, 950 ms, 5 m] #4
203:202
201:302
203:201
203:204
202:301
201:301
203:203
CheckPoints
RSSI
Seconds

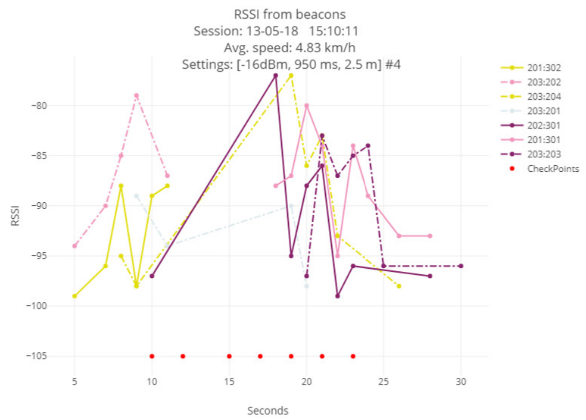

RSSI from beacons
Session: 13-05-18 14:04:30
Avg. speed: 4.3 km/h
Settings: [-16dBm, 950 ms, 5 m] #9
RSSI
Seconds
203:202
201:302
203:201
202:301
201:301
203:204
203:203
CheckPoints

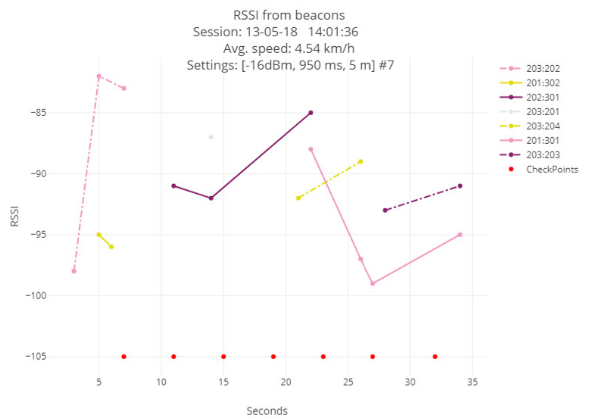

RSSI from beacons
Session: 13-05-18 15:08:01
Avg. speed: 5.01 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #2
RSSI
Seconds
203:201
203:202
201:302
203:204
201:301
202:301
203:203
CheckPoints

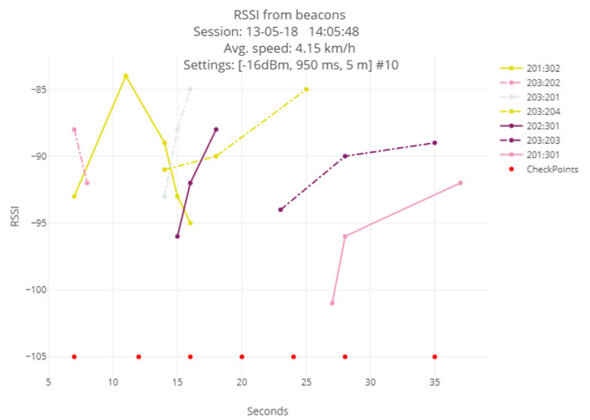

RSSI from beacons
Session: 13-05-18 15:11:43
Avg. speed: 4.91 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #5
RSSI
Seconds
203:202
203:201
203:204
203:203
201:301
202:301
CheckPoints

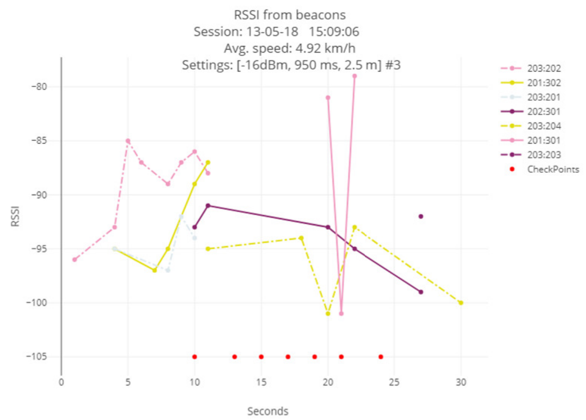

RSSI from beacons
Session: 13-05-18 14:03:11
Avg. speed: 4.29 km/h
Settings: [-16dBm, 950 ms, 5 m] #8
RSSI
Seconds
203:201
201:302
203:204
202:301
201:301
203:203
CheckPoints

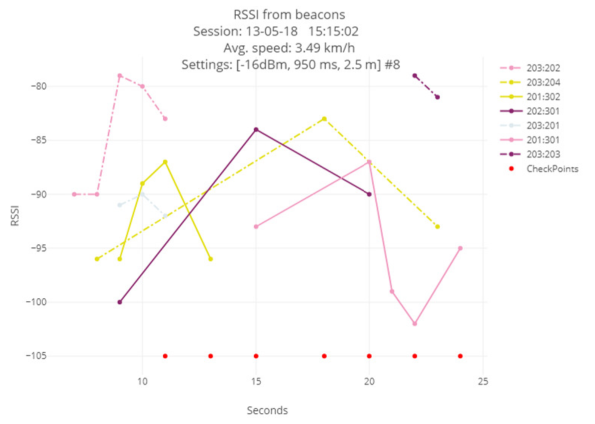

RSSI from beacons
Session: 13-05-18 15:06:53
Avg. speed: 4.09 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #1
RSSI
Seconds
203:202
201:302
203:201
203:204
202:301
201:301
203:203
CheckPoints

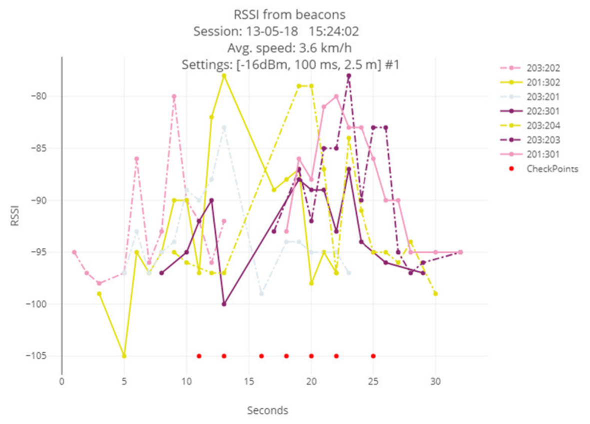

RSSI from beacons
Session: 13-05-18 15:10:11
Avg. speed: 4.83 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #4
RSSI
Seconds
201:302
203:202
203:204
203:201
202:301
201:301
203:203
CheckPoints

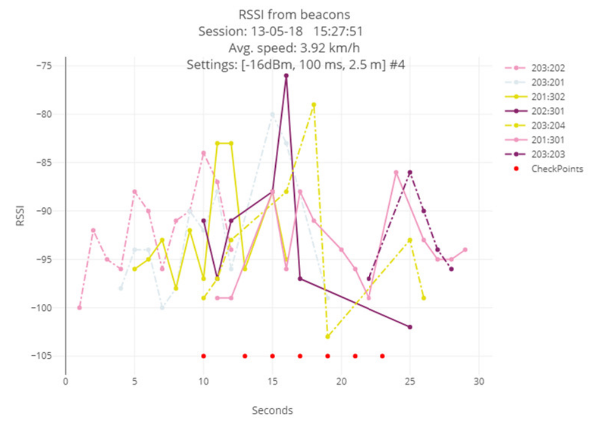

RSSI from beacons
Session: 13-05-18 14:01:36
Avg. speed: 4.54 km/h
Settings: [-16dBm, 950 ms, 5 m] #7
RSSI
Seconds
203:202
201:302
202:301
203:201
203:204
201:301
203:203
CheckPoints

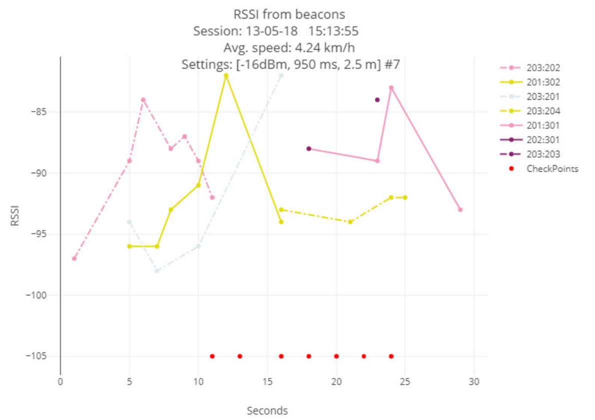

RSSI from beacons
Session: 13-05-18 14:05:48
Avg. speed: 4.15 km/h
Settings: [-16dBm, 950 ms, 5 m] #10
RSSI
Seconds
201:302
203:202
203:201
203:204
202:301
203:203
201:301
CheckPoints

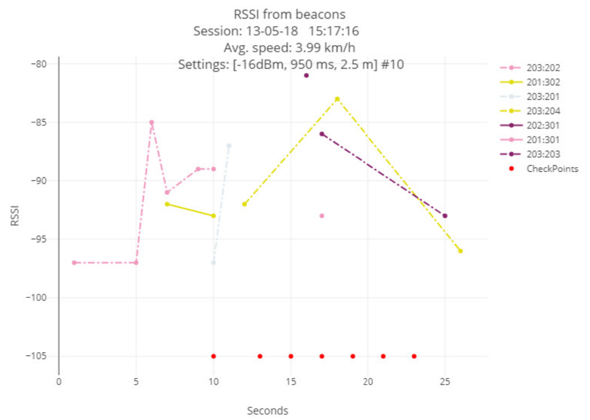

RSSI from beacons
Session: 13-05-18 15:09:06
Avg. speed: 4.92 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #3
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints

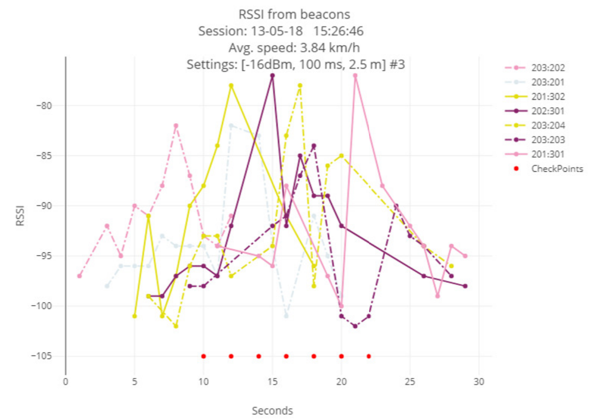

RSSI from beacons
Session: 13-05-18 15:15:02
Avg. speed: 3.49 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #8
RSSI
Seconds
203:202
203:204
201:302
202:301
203:201
201:301
203:203
CheckPoints

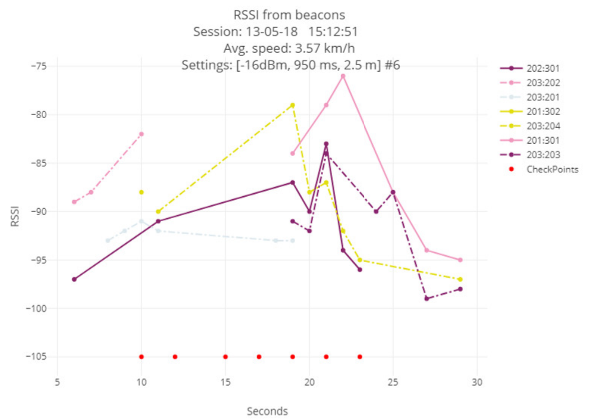

RSSI from beacons
Session: 13-05-18 15:24:02
Avg. speed: 3.6 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #1
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
203:203
201:301
CheckPoints

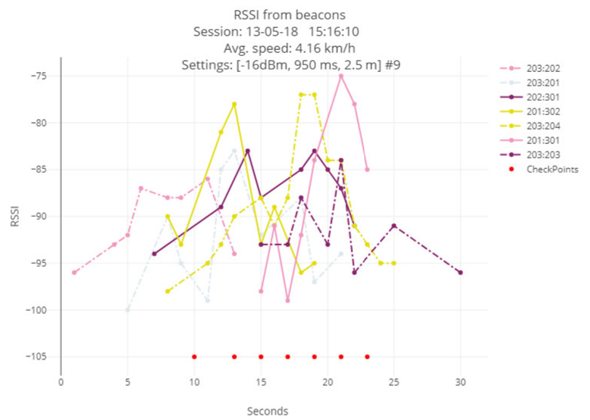

RSSI from beacons
Session: 13-05-18 15:27:51
Avg. speed: 3.92 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #4
RSSI
Seconds
203:202
203:201
201:302
202:301
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 15:13:55
Avg. speed: 4.24 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #7
RSSI
Seconds
203:202
201:302
203:201
203:204
201:301
202:301
203:203
CheckPoints

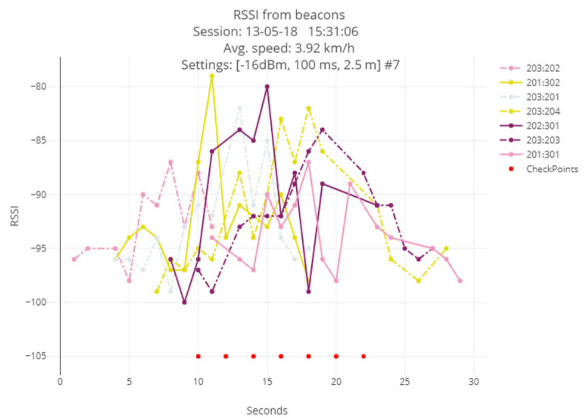

RSSI from beacons
Session: 13-05-18 15:17:16
Avg. speed: 3.99 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #10
RSSI
Seconds
203:202
201:302
203:201
203:204
202:301
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 15:26:46
Avg. speed: 3.84 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #3
RSSI
Seconds
203:202
203:201
201:302
202:301
203:204
203:203
201:301
CheckPoints


RSSI from beacons
Session: 13-05-18 15:12:51
Avg. speed: 3.57 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #6
RSSI
Seconds
202:301
203:202
203:201
201:302
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 15:16:10
Avg. speed: 4.16 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #9
RSSI
Seconds
203:202
203:201
202:301
201:302
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 15:25:21
Avg. speed: 3.56 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #2
RSSI
Seconds
203:202
203:201
201:302
203:204
202:301
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 15:31:06
Avg. speed: 3.92 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #7
RSSI
Seconds
203:202
201:302
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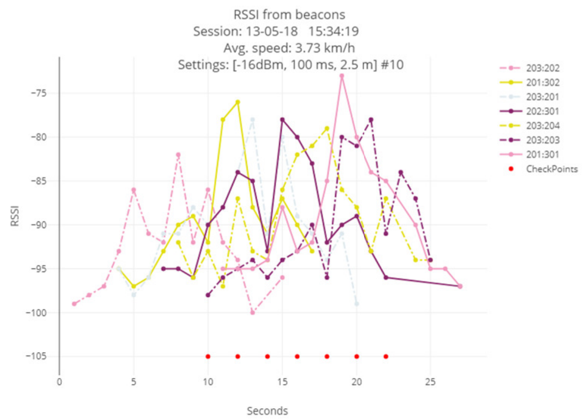
203:204
202:301
203:203
201:301
CheckPoints


RSSI from beacons
Session: 13-05-18 15:34:19
Avg. speed: 3.73 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #10
RSSI
Seconds
203:202
201:302
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202:301
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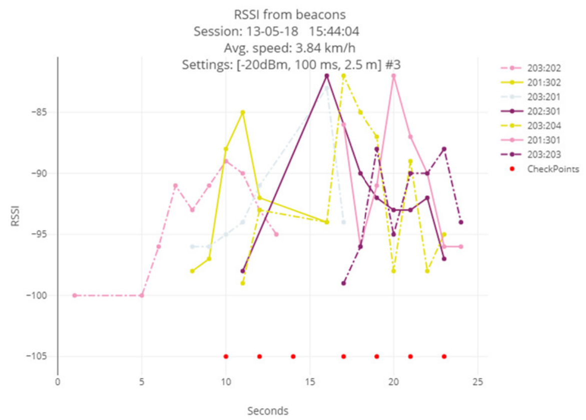
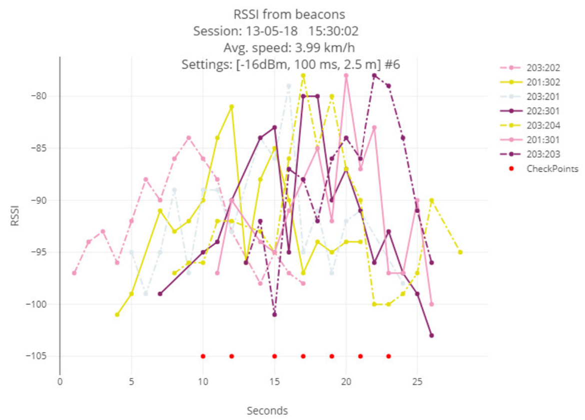
203:203
201:301
CheckPoints


RSSI from beacons
Session: 13-05-18 15:44:04
Avg. speed: 3.84 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #3
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 15:30:02
Avg. speed: 3.99 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #6
RSSI
Seconds
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201:301
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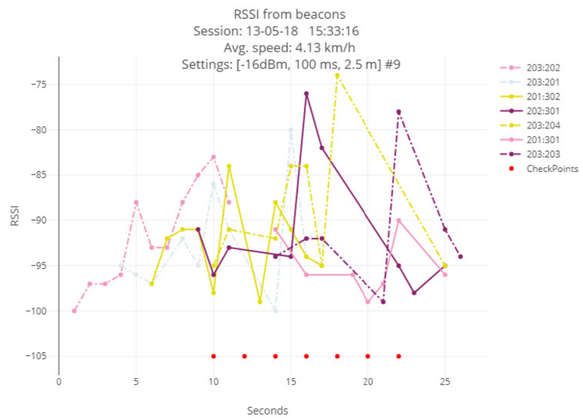
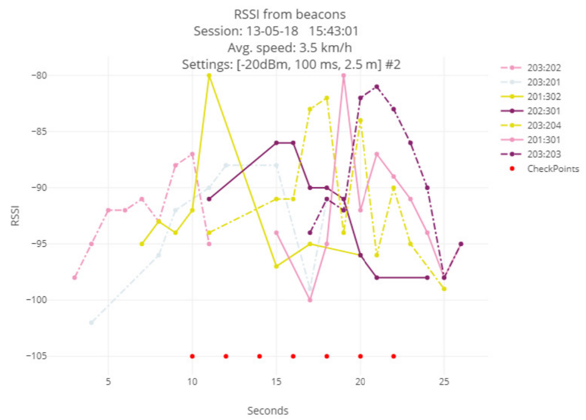
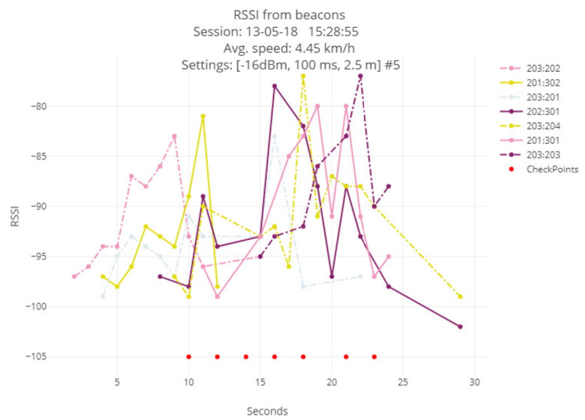
CheckPoints


RSSI from beacons
Session: 13-05-18 15:33:16
Avg. speed: 4.13 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #9
RSSI
Seconds
203:202
203:201
201:302
202:301
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 15:43:01
Avg. speed: 3.5 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #2
RSSI
Seconds
203:202
203:201
201:302
202:301
203:204
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 15:28:55
Avg. speed: 4.45 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #5
RSSI
Seconds
203:202
201:302
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202:301
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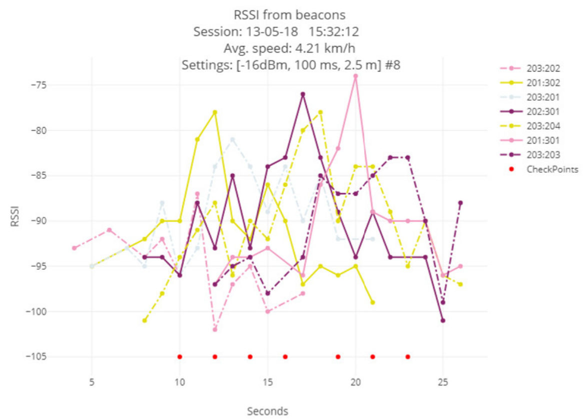
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 15:32:12
Avg. speed: 4.21 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #8
RSSI
Seconds
203:202
201:302
203:201
202:301
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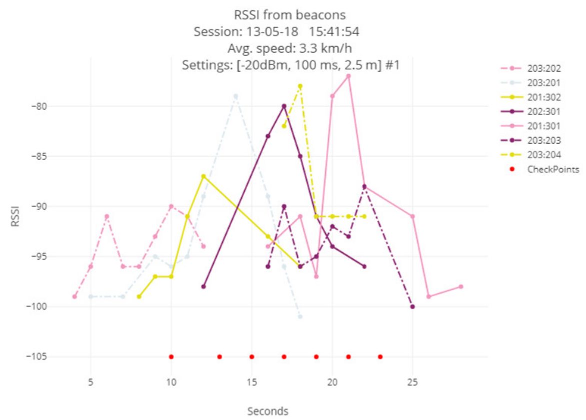
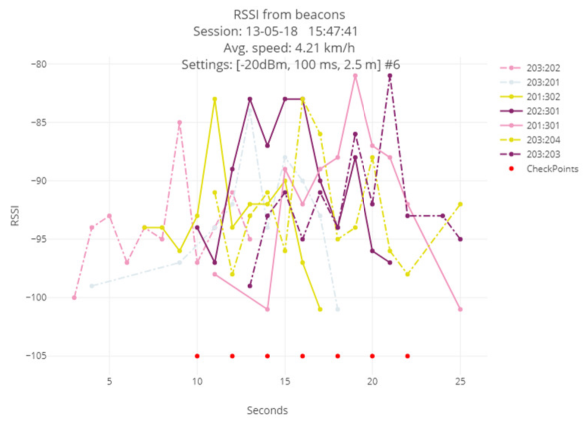
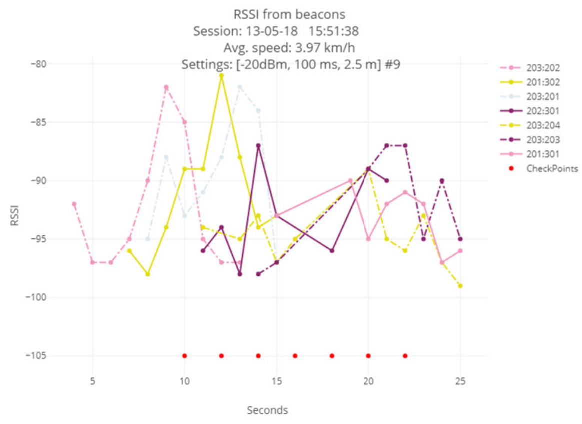
201:301
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 15:41:54
Avg. speed: 3.3 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #1
RSSI
Seconds
203:202
203:201
201:302
202:301
201:301
203:203
203:204
CheckPoints


RSSI from beacons
Session: 13-05-18 15:47:41
Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #6
RSSI
Seconds
203:202
203:201
201:302
202:301
201:301
203:204
203:203
CheckPoints


RSSI from beacons
Session: 13-05-18 15:51:38
Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #9
RSSI
Seconds
203:202
201:302
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202:301
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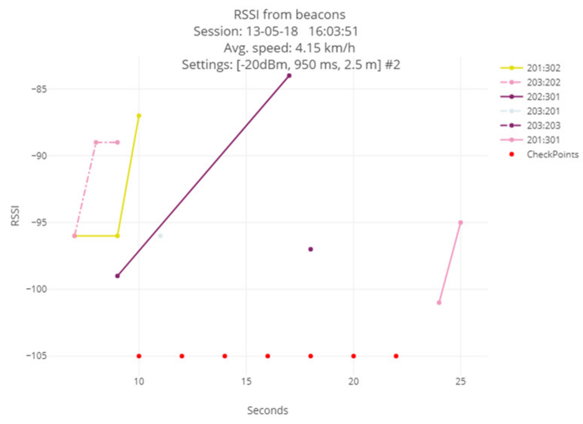
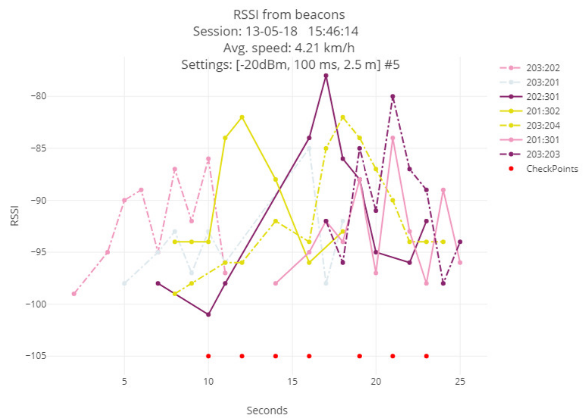
203:203
201:301
CheckPoints


RSSI from beacons
Session: 13-05-18 16:03:51
Avg. speed: 4.15 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #2
RSSI
Seconds
201:302
203:202
202:301
203:201
203:203
201:301
CheckPoints


RSSI from beacons
Session: 13-05-18 15:46:14
Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #5
RSSI
Seconds
203:202
203:201
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201:302
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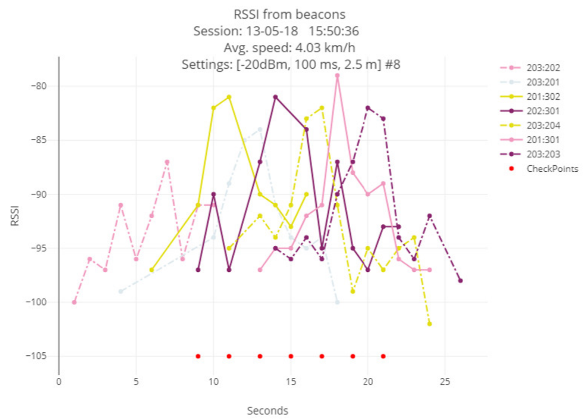
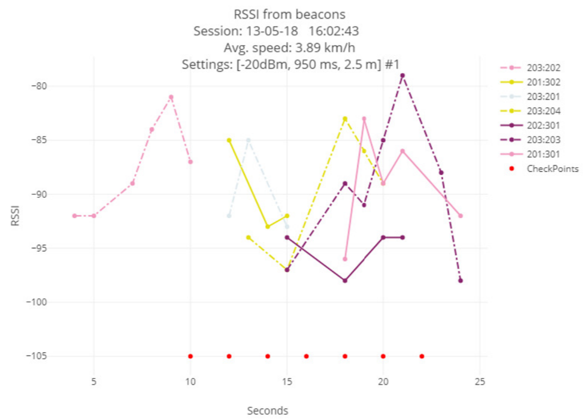
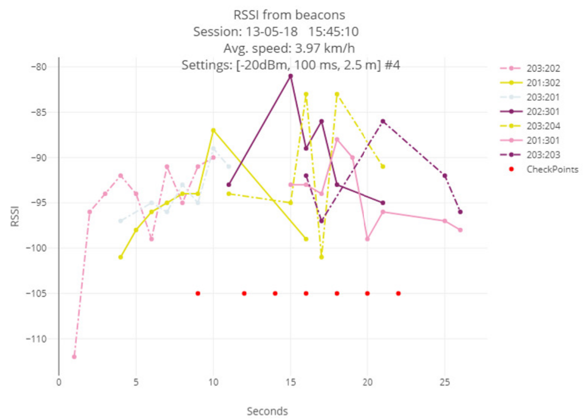
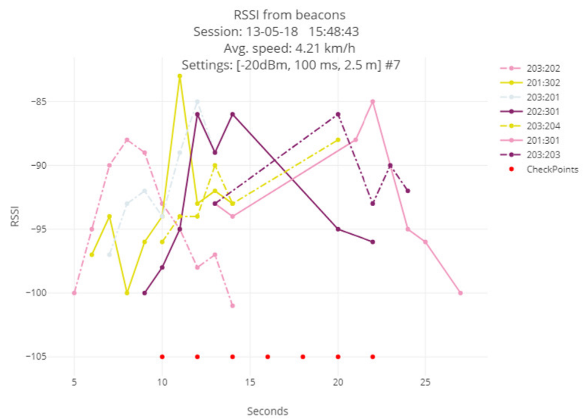
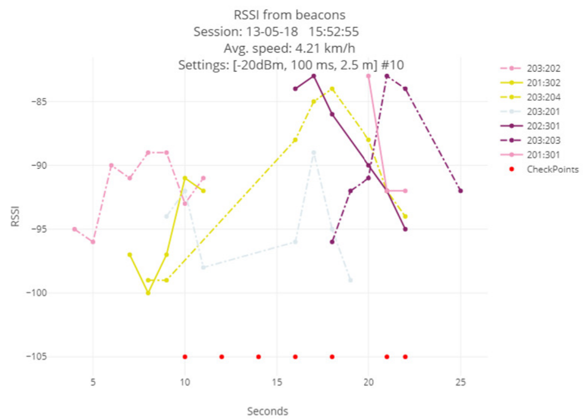
203:203
CheckPoints

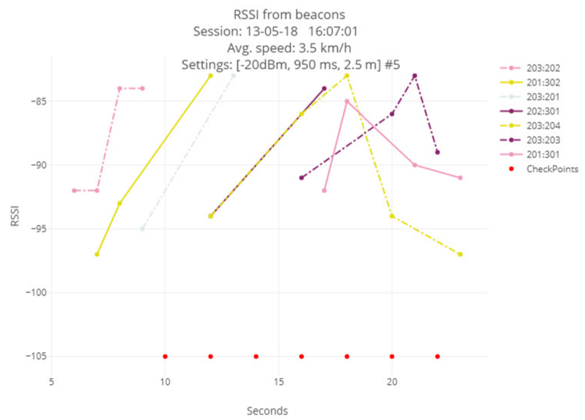

RSSI from beacons
Session: 13-05-18 15:50:36
Avg. speed: 4.03 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #8
RSSI
Seconds
203:202
203:201
201:302
202:301
203:204
201:301
203:203
CheckPoints

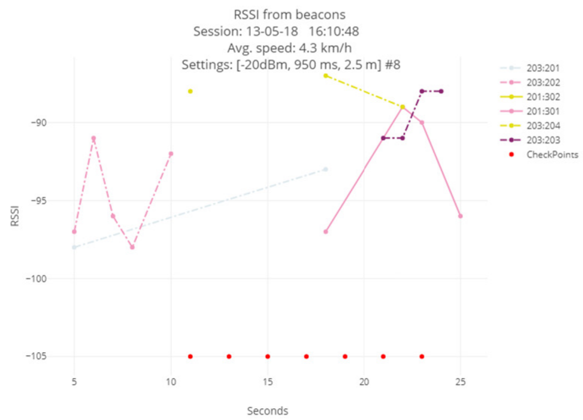

RSSI from beacons
Session: 13-05-18 16:02:43
Avg. speed: 3.89 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #1
RSSI
Seconds
203:202
201:302
203:201
203:204
202:301
203:203
201:301
CheckPoints

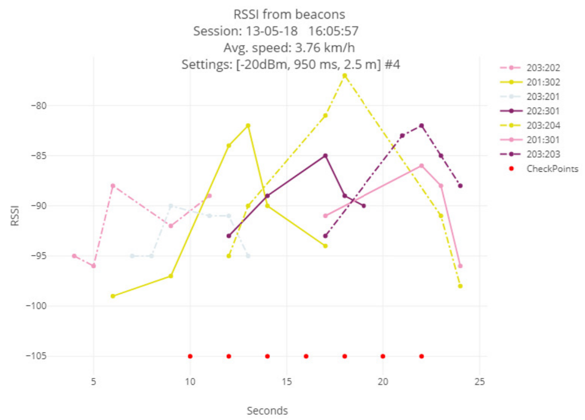

RSSI from beacons
Session: 13-05-18 15:45:10
Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #4
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints

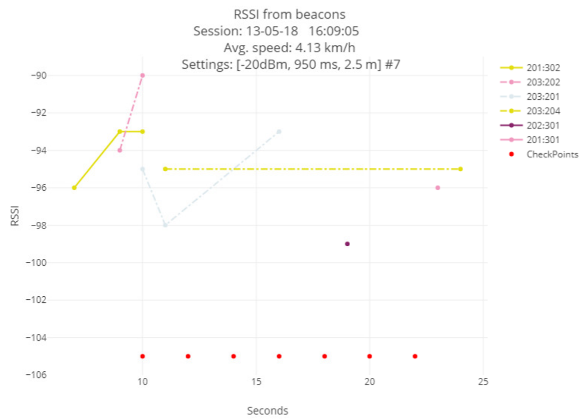

RSSI from beacons
Session: 13-05-18 15:48:43
Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #7
RSSI
Seconds
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints

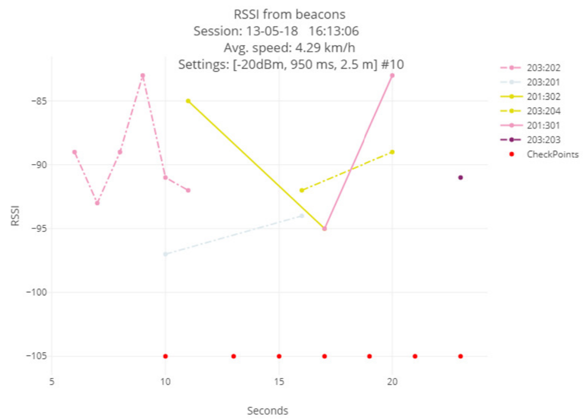

RSSI from beacons
Session: 13-05-18 15:52:55
Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #10
RSSI
Seconds
203:202
201:302
203:204
203:201
202:301
203:203
201:301
CheckPoints

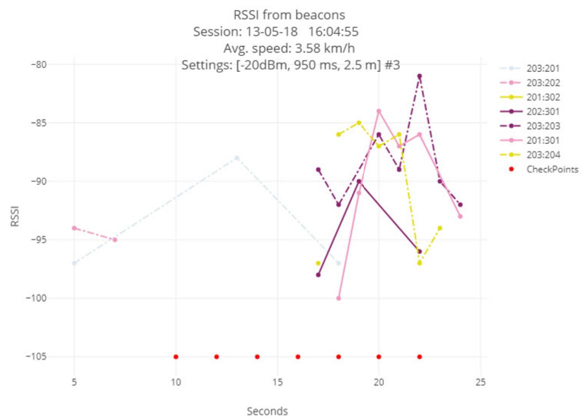

RSSI from beacons
Session: 13-05-18 16:07:01
Avg. speed: 3.5 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #5
203:202
201:302
203:201
202:301
203:204
203:203
201:301
CheckPoints
RSSI
Seconds

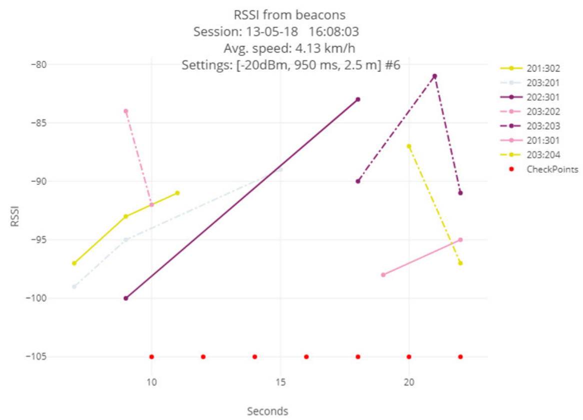

RSSI from beacons
Session: 13-05-18 16:10:48
Avg. speed: 4.3 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #8
203:201
203:202
201:302
201:301
203:204
203:203
CheckPoints
RSSI
Seconds

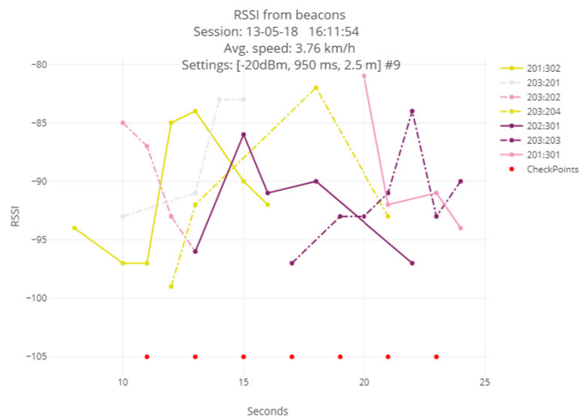

RSSI from beacons
Session: 13-05-18 16:05:57
Avg. speed: 3.76 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #4
203:202
201:302
203:201
202:301
203:204
201:301
203:203
CheckPoints
RSSI
Seconds


RSSI from beacons
Session: 13-05-18 16:09:05
Avg. speed: 4.13 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #7
201:302
203:202
203:201
203:204
202:301
201:301
CheckPoints
RSSI
Seconds


RSSI from beacons
Session: 13-05-18 16:13:06
Avg. speed: 4.29 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #10
203:202
203:201
201:302
203:204
201:301
203:203
CheckPoints
RSSI
Seconds


RSSI from beacons
Session: 13-05-18 16:04:55
Avg. speed: 3.58 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #3
203:201
203:202
201:302
202:301
203:203
201:301
203:204
CheckPoints
RSSI
Seconds

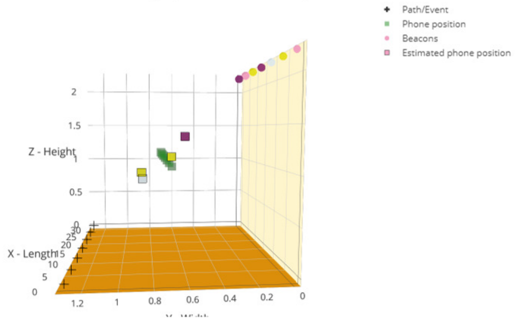

RSSI from beacons
Session: 13-05-18 16:08:03
Avg. speed: 4.13 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #6
201:302
203:201
202:301
203:202
203:203
201:301
203:204
CheckPoints
RSSI
Seconds


RSSI from beacons
Session: 13-05-18 16:11:54
Avg. speed: 3.76 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #9
201:302
203:201
203:202
203:204
202:301
203:203
201:301
CheckPoints
RSSI
Seconds

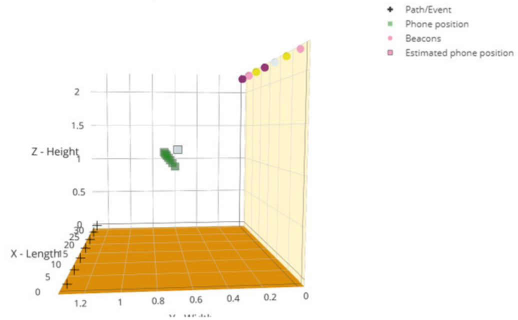
11.1.3 Estimated phone position 3D-graphs

The attachment is on the next page(s).

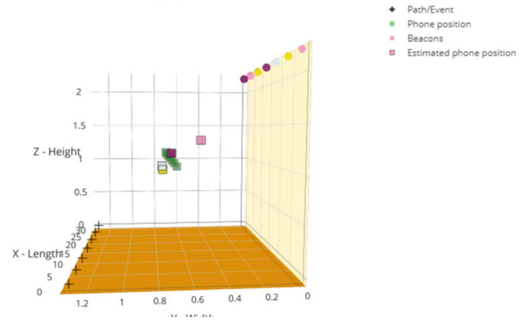
Estimated position of phone
Session: 13-05-18 12:38:43 Avg. speed: 4.49 km/h
Settings: [-20dBm, 950 ms, 5 m] #3



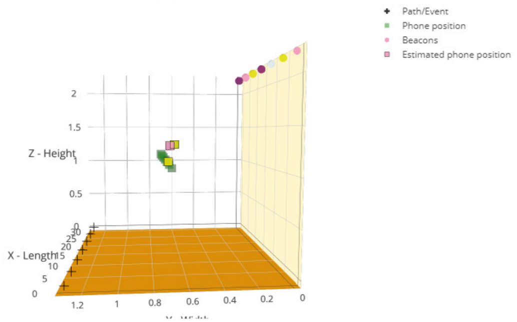
Estimated position of phone
Session: 13-05-18 12:43:58 Avg. speed: 4.23 km/h
Settings: [-20dBm, 950 ms, 5 m] #6



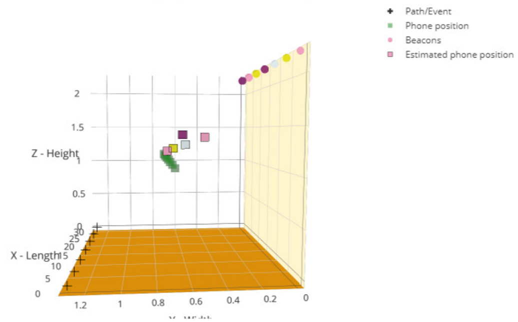
Estimated position of phone
Session: 13-05-18 12:47:58 Avg. speed: 5.02 km/h
Settings: [-20dBm, 950 ms, 5 m] #9



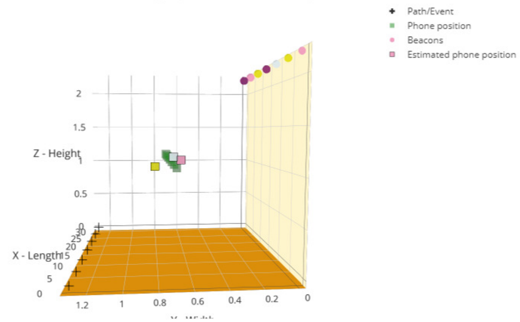
Estimated position of phone
Session: 13-05-18 12:37:22 Avg. speed: 4.42 km/h
Settings: [-20dBm, 950 ms, 5 m] #2



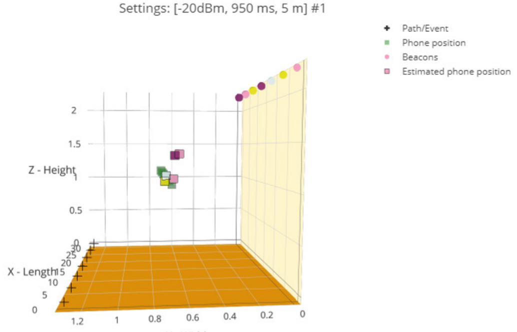
Estimated position of phone
Session: 13-05-18 12:42:33 Avg. speed: 4.55 km/h
Settings: [-20dBm, 950 ms, 5 m] #5



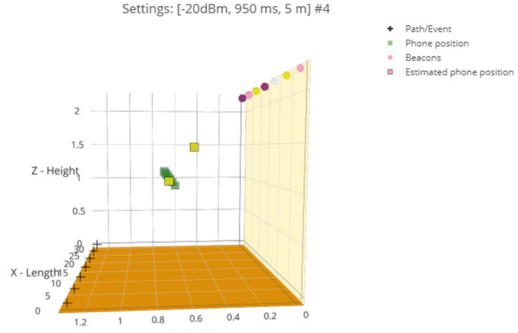
Estimated position of phone
Session: 13-05-18 12:46:35 Avg. speed: 4.08 km/h
Settings: [-20dBm, 950 ms, 5 m] #8



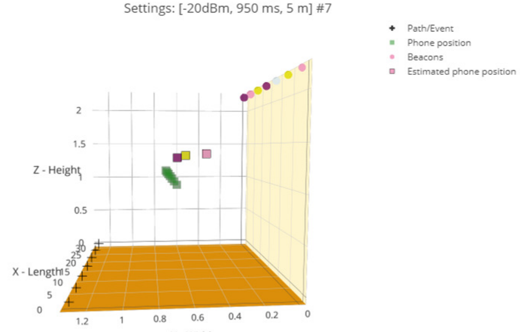
Estimated position of phone
Session: 13-05-18 12:36:04 Avg. speed: 3.88 km/h
Settings: [-20dBm, 950 ms, 5 m] #1

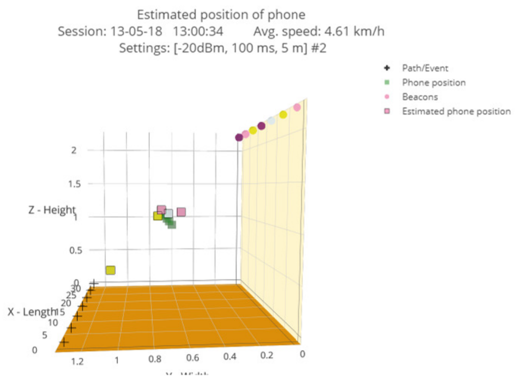


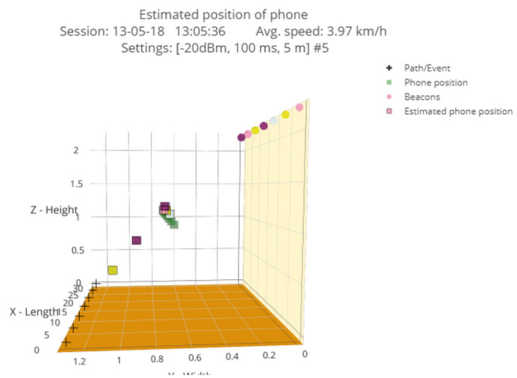
Estimated position of phone
Session: 13-05-18 12:41:12 Avg. speed: 5.11 km/h
Settings: [-20dBm, 950 ms, 5 m] #4

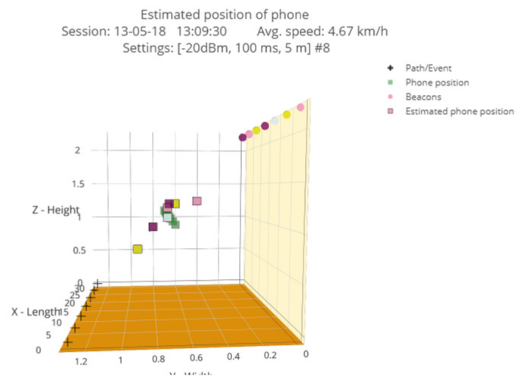


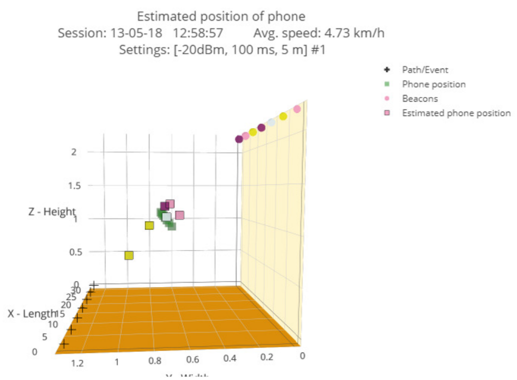
Estimated position of phone
Session: 13-05-18 12:45:17 Avg. speed: 4.55 km/h
Settings: [-20dBm, 950 ms, 5 m] #7

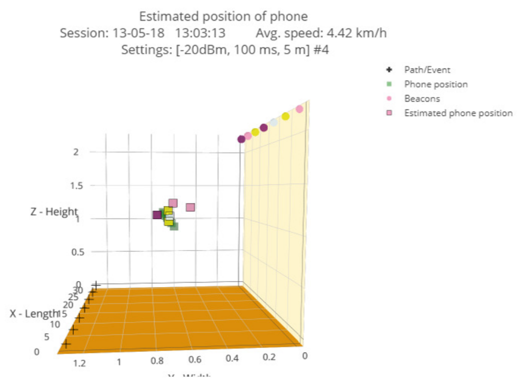


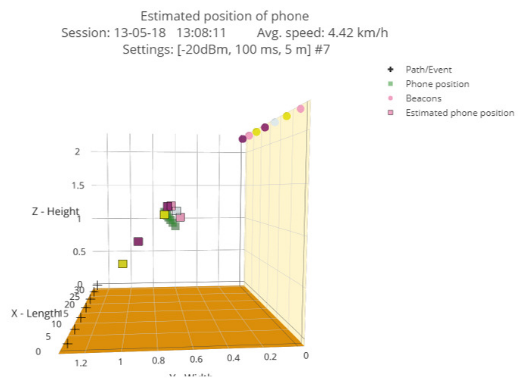

Estimated position of phone
Session: 13-05-18 13:00:34 Avg. speed: 4.61 km/h
Settings: [-20dBm, 100 ms, 5 m] #2
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

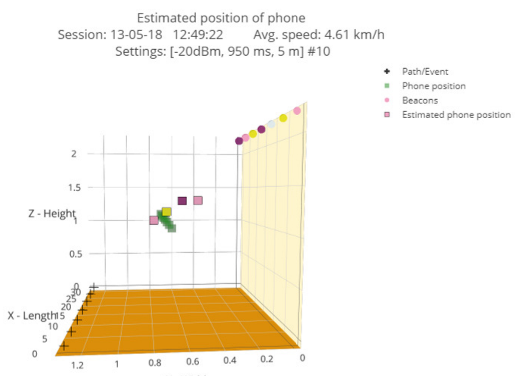

Estimated position of phone
Session: 13-05-18 13:05:36 Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 5 m] #5
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

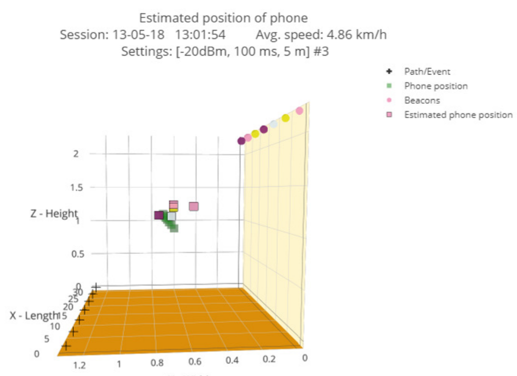

Estimated position of phone
Session: 13-05-18 13:09:30 Avg. speed: 4.67 km/h
Settings: [-20dBm, 100 ms, 5 m] #8
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

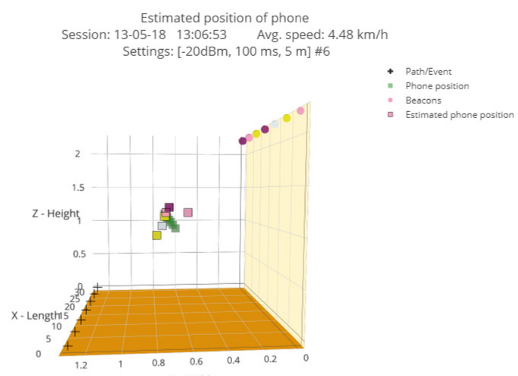

Estimated position of phone
Session: 13-05-18 12:58:57 Avg. speed: 4.73 km/h
Settings: [-20dBm, 100 ms, 5 m] #1
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 13:03:13 Avg. speed: 4.42 km/h
Settings: [-20dBm, 100 ms, 5 m] #4
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

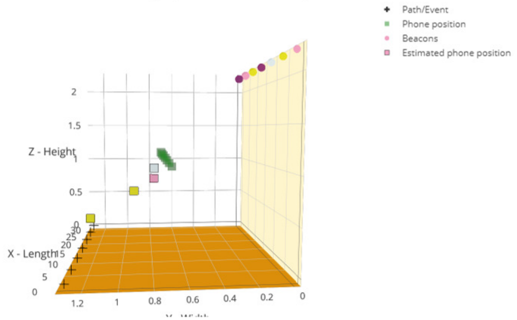

Estimated position of phone
Session: 13-05-18 13:08:11 Avg. speed: 4.42 km/h
Settings: [-20dBm, 100 ms, 5 m] #7
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 12:49:22 Avg. speed: 4.61 km/h
Settings: [-20dBm, 950 ms, 5 m] #10
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

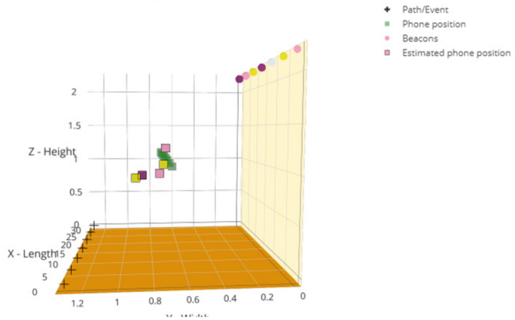

Estimated position of phone
Session: 13-05-18 13:01:54 Avg. speed: 4.86 km/h
Settings: [-20dBm, 100 ms, 5 m] #3
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 13:06:53 Avg. speed: 4.48 km/h
Settings: [-20dBm, 100 ms, 5 m] #6
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

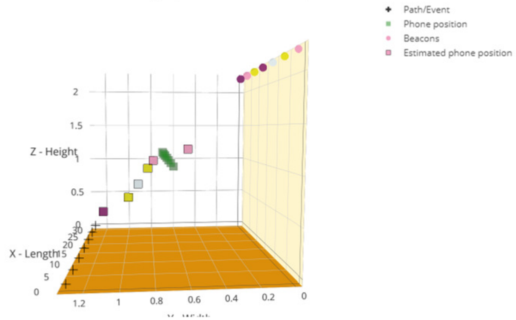
Estimated position of phone
Session: 13-05-18 13:31:56 Avg. speed: 4.85 km/h
Settings: [-16dBm, 100 ms, 5 m] #1



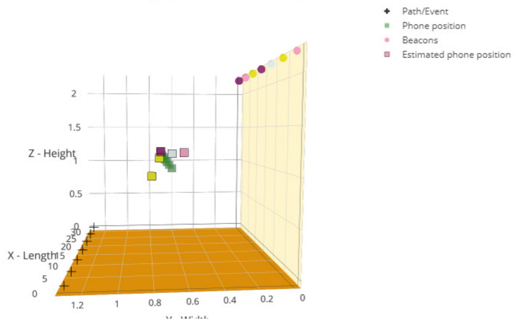
Estimated position of phone
Session: 13-05-18 13:36:46 Avg. speed: 4.61 km/h
Settings: [-16dBm, 100 ms, 5 m] #4



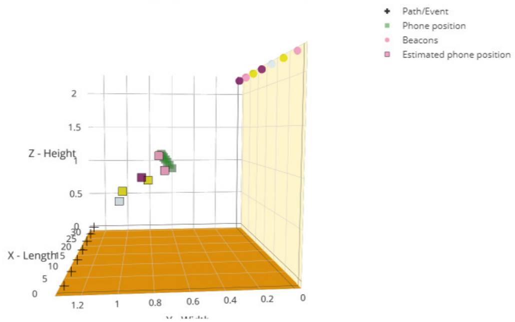
Estimated position of phone
Session: 13-05-18 13:41:23 Avg. speed: 4.48 km/h
Settings: [-16dBm, 100 ms, 5 m] #7



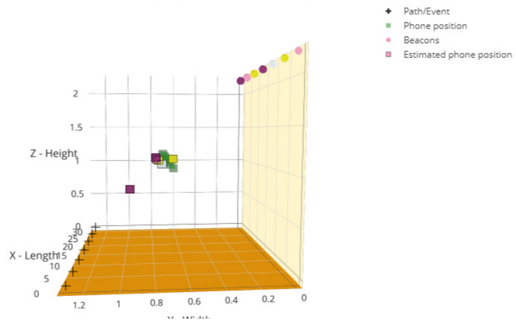
Estimated position of phone
Session: 13-05-18 13:12:05 Avg. speed: 4.54 km/h
Settings: [-20dBm, 100 ms, 5 m] #10



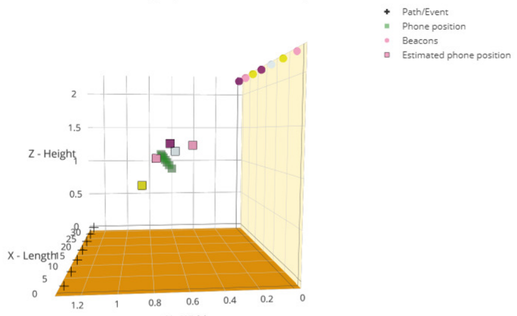
Estimated position of phone
Session: 13-05-18 13:34:51 Avg. speed: 4.86 km/h
Settings: [-16dBm, 100 ms, 5 m] #3



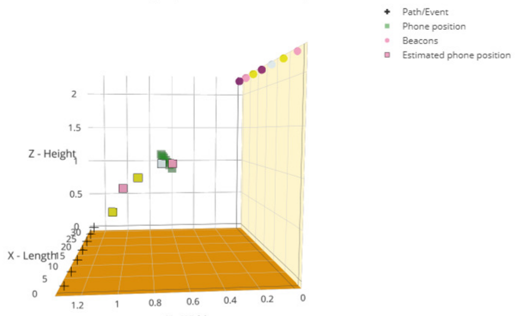
Estimated position of phone
Session: 13-05-18 13:40:08 Avg. speed: 4.28 km/h
Settings: [-16dBm, 100 ms, 5 m] #6



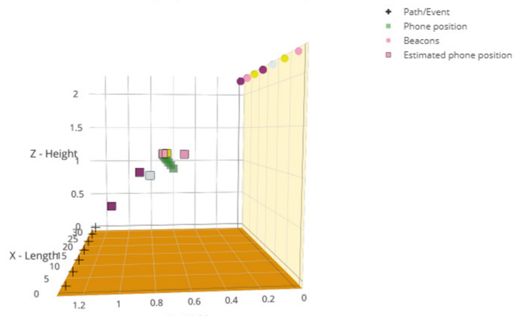
Estimated position of phone
Session: 13-05-18 13:10:48 Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 5 m] #9

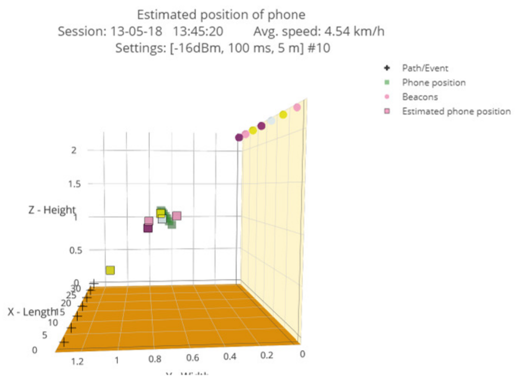


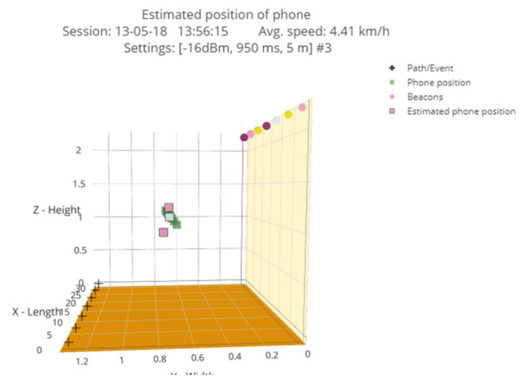
Estimated position of phone
Session: 13-05-18 13:33:18 Avg. speed: 5.06 km/h
Settings: [-16dBm, 100 ms, 5 m] #2

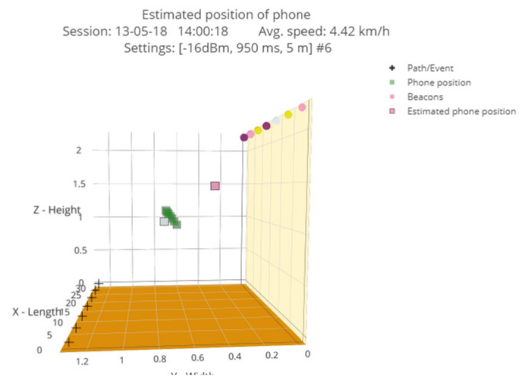


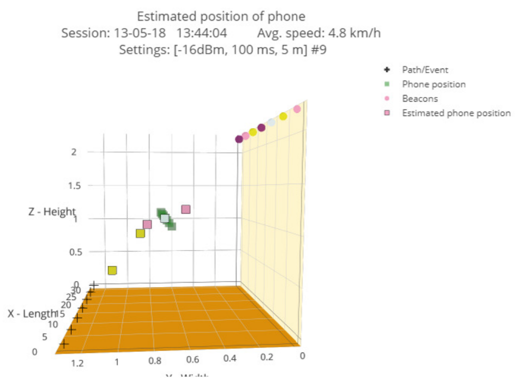
Estimated position of phone
Session: 13-05-18 13:38:04 Avg. speed: 4.67 km/h
Settings: [-16dBm, 100 ms, 5 m] #5

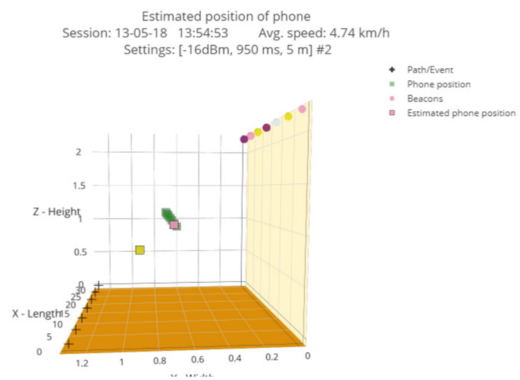


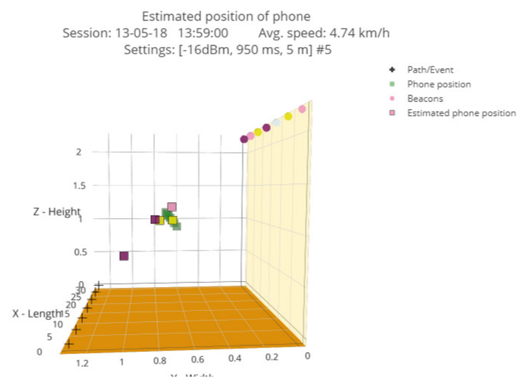

Estimated position of phone
Session: 13-05-18 13:45:20 Avg. speed: 4.54 km/h
Settings: [-16dBm, 100 ms, 5 m] #10
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

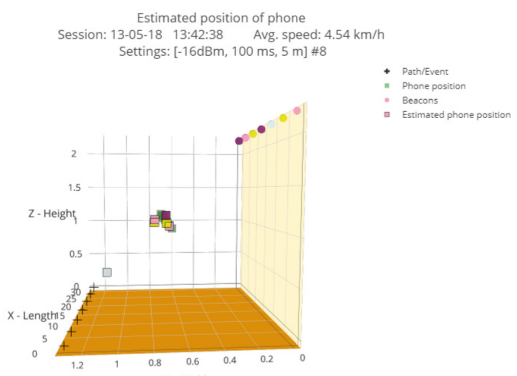

Estimated position of phone
Session: 13-05-18 13:56:15 Avg. speed: 4.41 km/h
Settings: [-16dBm, 950 ms, 5 m] #3
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

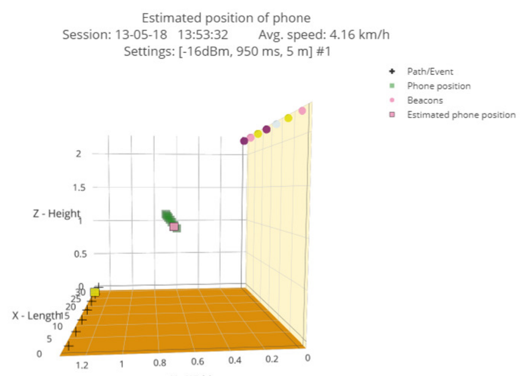

Estimated position of phone
Session: 13-05-18 14:00:18 Avg. speed: 4.42 km/h
Settings: [-16dBm, 950 ms, 5 m] #6
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

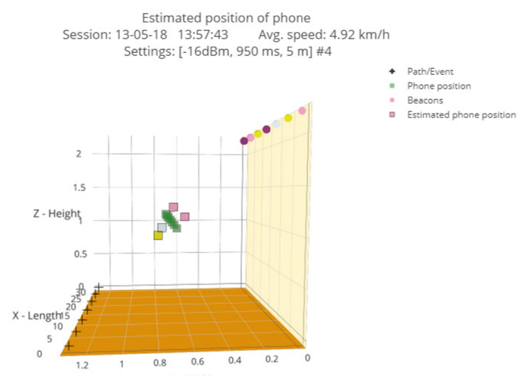

Estimated position of phone
Session: 13-05-18 13:44:04 Avg. speed: 4.8 km/h
Settings: [-16dBm, 100 ms, 5 m] #9
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

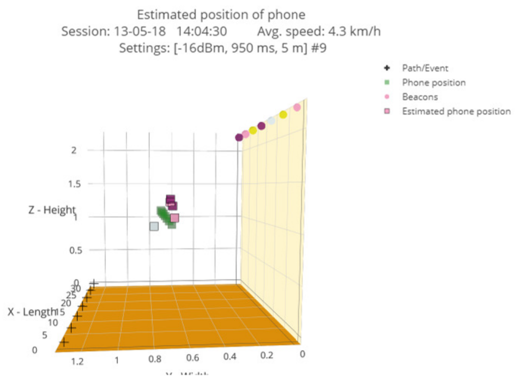

Estimated position of phone
Session: 13-05-18 13:54:53 Avg. speed: 4.74 km/h
Settings: [-16dBm, 950 ms, 5 m] #2
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

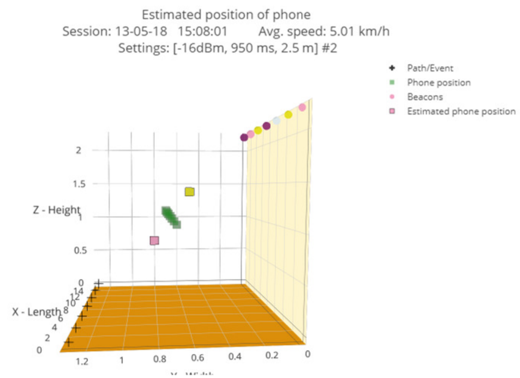

Estimated position of phone
Session: 13-05-18 13:59:00 Avg. speed: 4.74 km/h
Settings: [-16dBm, 950 ms, 5 m] #5
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

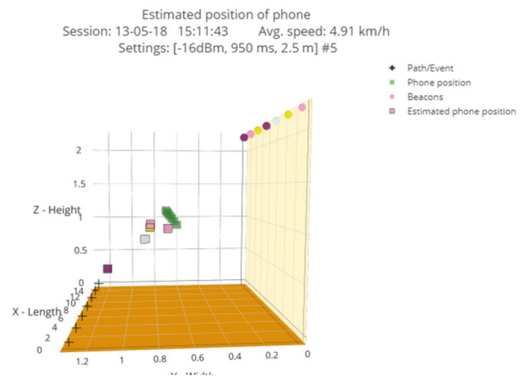

Estimated position of phone
Session: 13-05-18 13:42:38 Avg. speed: 4.54 km/h
Settings: [-16dBm, 100 ms, 5 m] #8
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

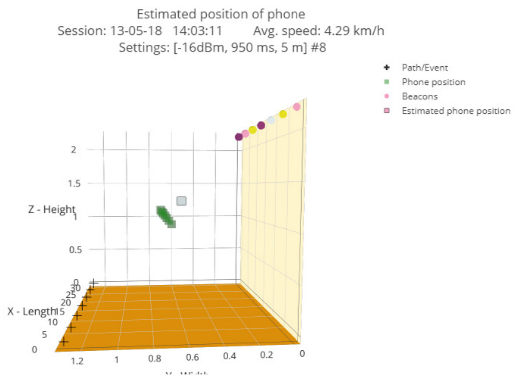

Estimated position of phone
Session: 13-05-18 13:53:32 Avg. speed: 4.16 km/h
Settings: [-16dBm, 950 ms, 5 m] #1
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

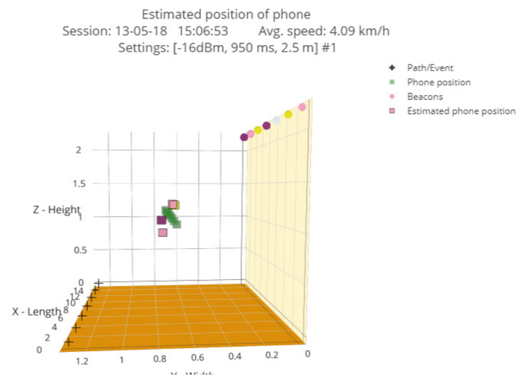

Estimated position of phone
Session: 13-05-18 13:57:43 Avg. speed: 4.92 km/h
Settings: [-16dBm, 950 ms, 5 m] #4
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

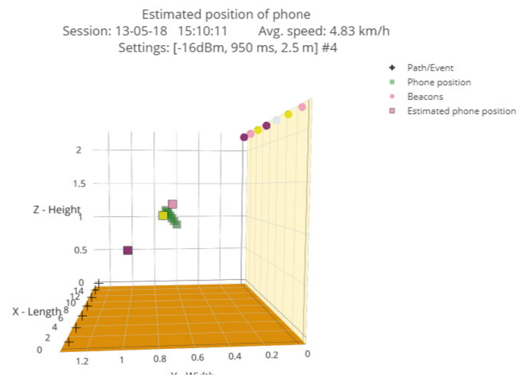

Estimated position of phone
Session: 13-05-18 14:04:30 Avg. speed: 4.3 km/h
Settings: [-16dBm, 950 ms, 5 m] #9
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

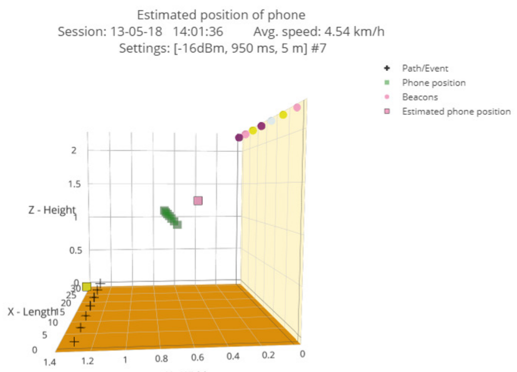

Estimated position of phone
Session: 13-05-18 15:08:01 Avg. speed: 5.01 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #2
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

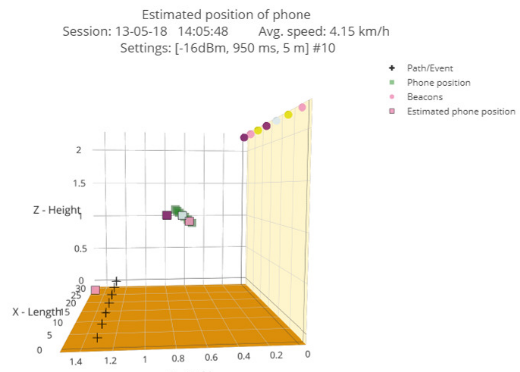

Estimated position of phone
Session: 13-05-18 15:11:43 Avg. speed: 4.91 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #5
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

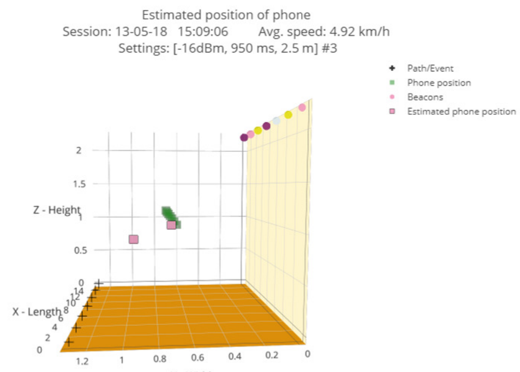

Estimated position of phone
Session: 13-05-18 14:03:11 Avg. speed: 4.29 km/h
Settings: [-16dBm, 950 ms, 5 m] #8
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 15:06:53 Avg. speed: 4.09 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #1
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

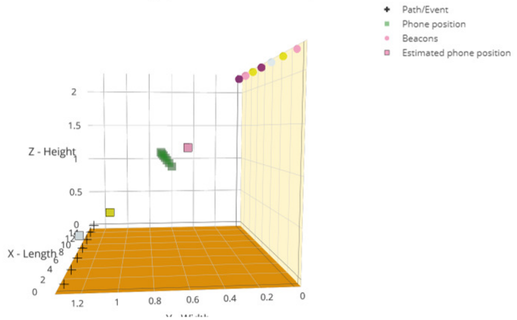

Estimated position of phone
Session: 13-05-18 15:10:11 Avg. speed: 4.83 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #4
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 14:01:36 Avg. speed: 4.54 km/h
Settings: [-16dBm, 950 ms, 5 m] #7
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

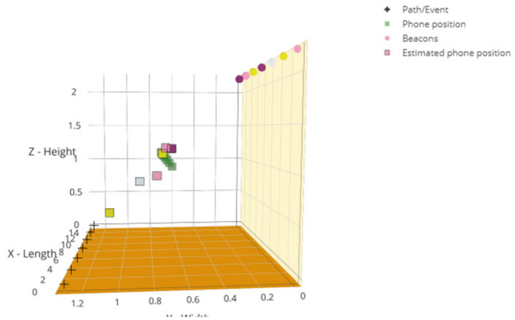

Estimated position of phone
Session: 13-05-18 14:05:48 Avg. speed: 4.15 km/h
Settings: [-16dBm, 950 ms, 5 m] #10
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 15:09:06 Avg. speed: 4.92 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #3
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

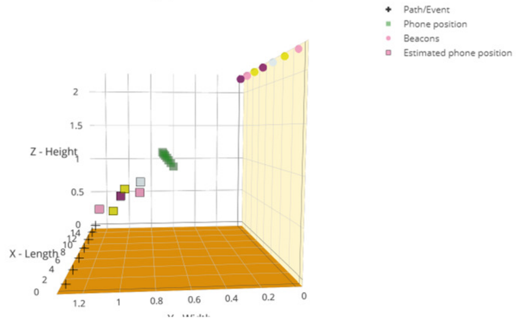
Estimated position of phone
Session: 13-05-18 15:15:02 Avg. speed: 3.49 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #8



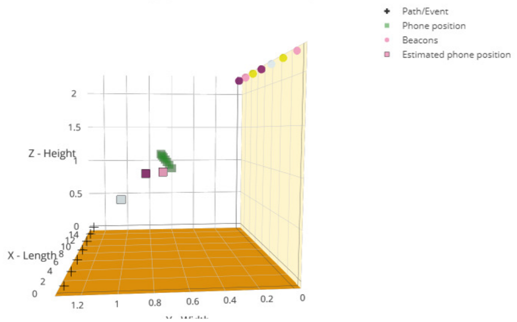
Estimated position of phone
Session: 13-05-18 15:24:02 Avg. speed: 3.6 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #1



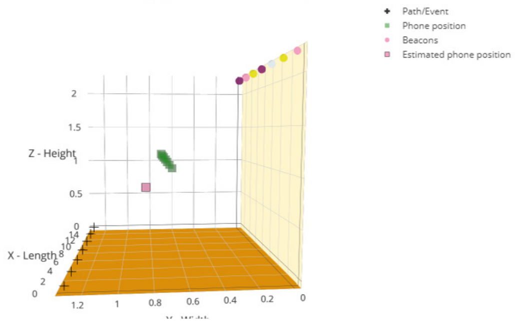
Estimated position of phone
Session: 13-05-18 15:27:51 Avg. speed: 3.92 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #4



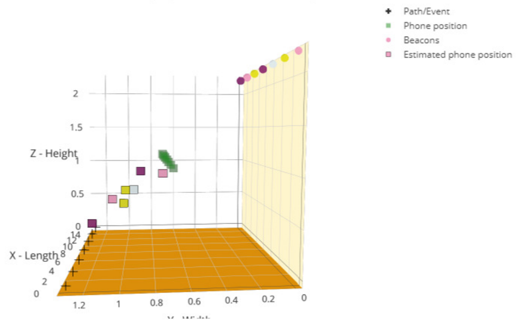
Estimated position of phone
Session: 13-05-18 15:13:55 Avg. speed: 4.24 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #7



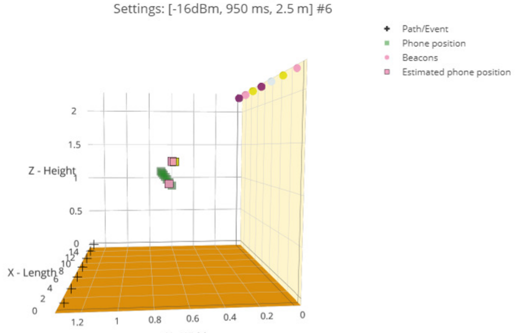
Estimated position of phone
Session: 13-05-18 15:17:16 Avg. speed: 3.99 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #10



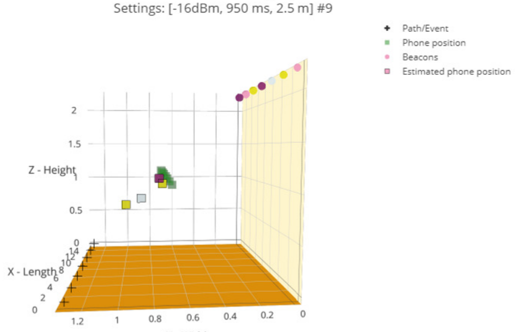
Estimated position of phone
Session: 13-05-18 15:26:46 Avg. speed: 3.84 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #3



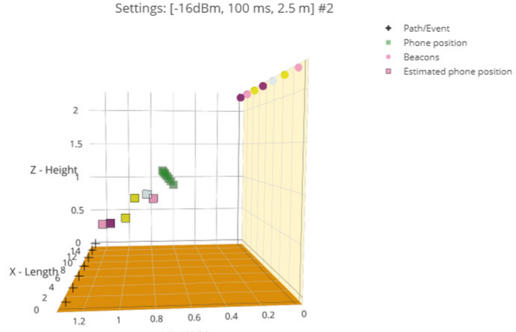
Estimated position of phone
Session: 13-05-18 15:12:51 Avg. speed: 3.57 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #6

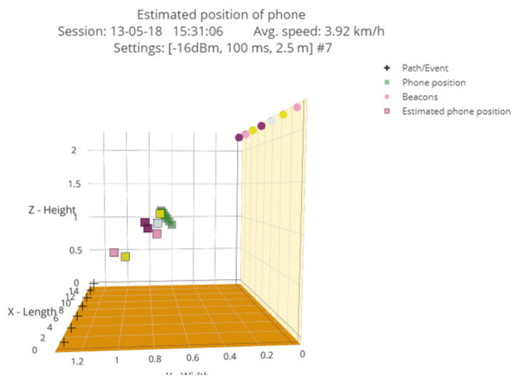


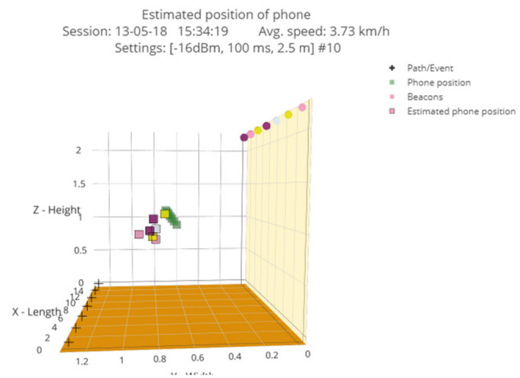
Estimated position of phone
Session: 13-05-18 15:16:10 Avg. speed: 4.16 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #9

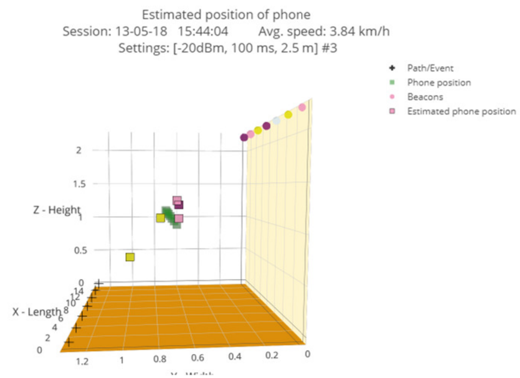


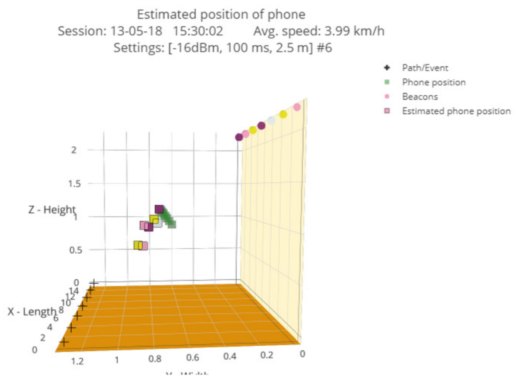
Estimated position of phone
Session: 13-05-18 15:25:21 Avg. speed: 3.56 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #2

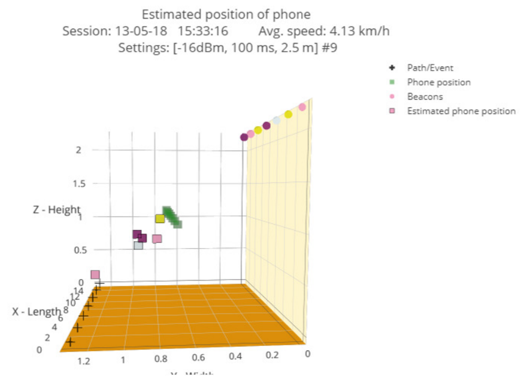


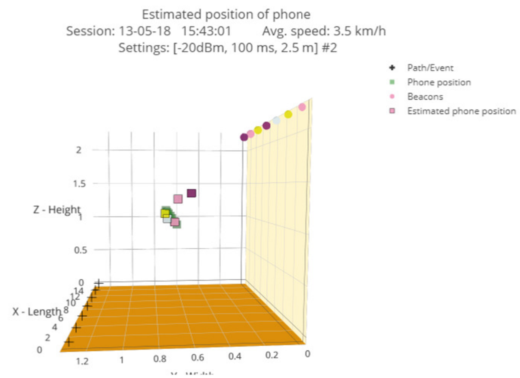

Estimated position of phone
Session: 13-05-18 15:31:06 Avg. speed: 3.92 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #7
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

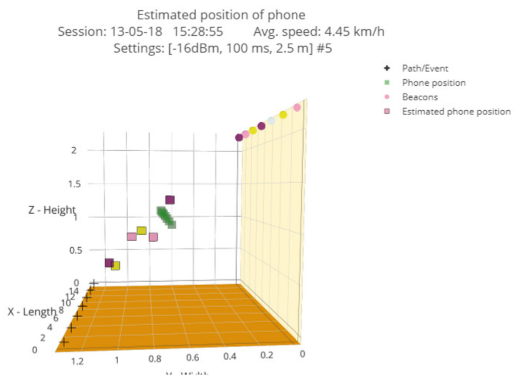

Estimated position of phone
Session: 13-05-18 15:34:19 Avg. speed: 3.73 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #10
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

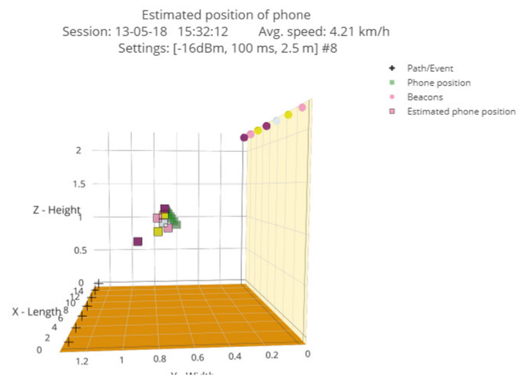

Estimated position of phone
Session: 13-05-18 15:44:04 Avg. speed: 3.84 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #3
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

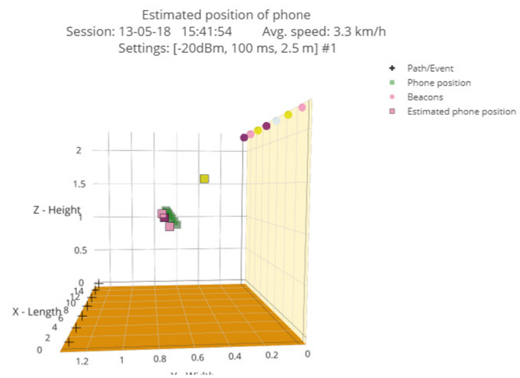

Estimated position of phone
Session: 13-05-18 15:30:02 Avg. speed: 3.99 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #6
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 15:33:16 Avg. speed: 4.13 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #9
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

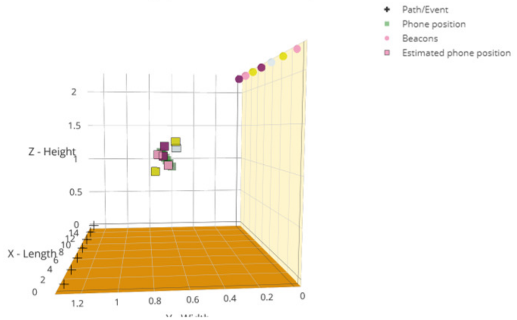

Estimated position of phone
Session: 13-05-18 15:43:01 Avg. speed: 3.5 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #2
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 15:28:55 Avg. speed: 4.45 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #5
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

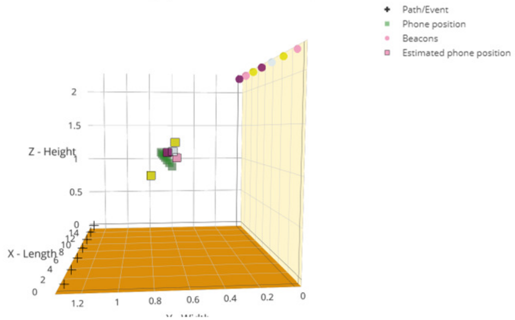

Estimated position of phone
Session: 13-05-18 15:32:12 Avg. speed: 4.21 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #8
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 15:41:54 Avg. speed: 3.3 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #1
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

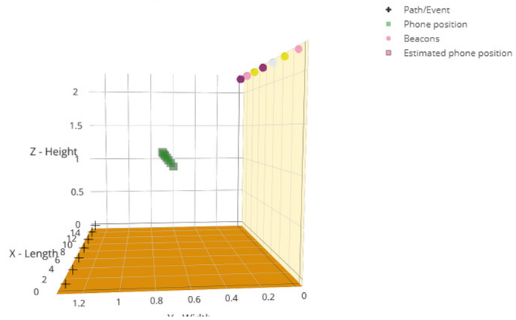
Estimated position of phone
Session: 13-05-18 15:47:41 Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #6



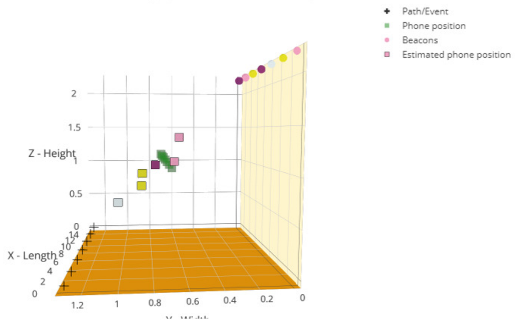
Estimated position of phone
Session: 13-05-18 15:51:38 Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #9



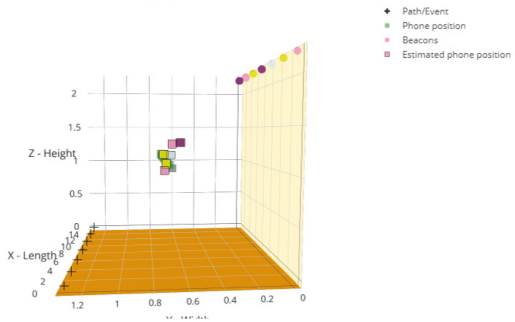
Estimated position of phone
Session: 13-05-18 16:03:51 Avg. speed: 4.15 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #2



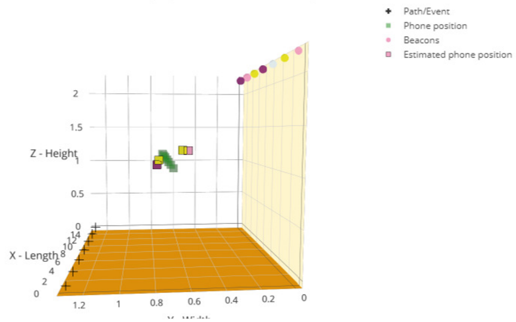
Estimated position of phone
Session: 13-05-18 15:46:14 Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #5



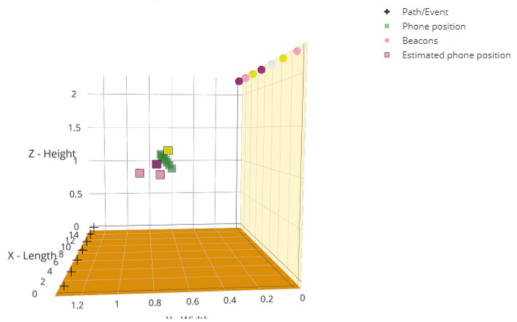
Estimated position of phone
Session: 13-05-18 15:50:36 Avg. speed: 4.03 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #8



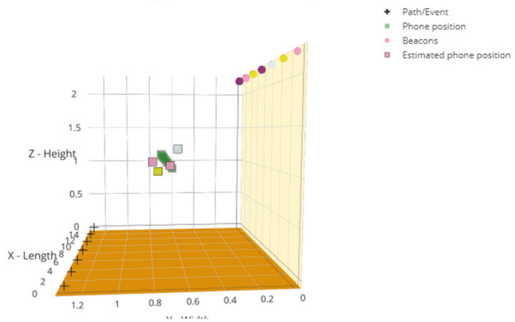
Estimated position of phone
Session: 13-05-18 16:02:43 Avg. speed: 3.89 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #1



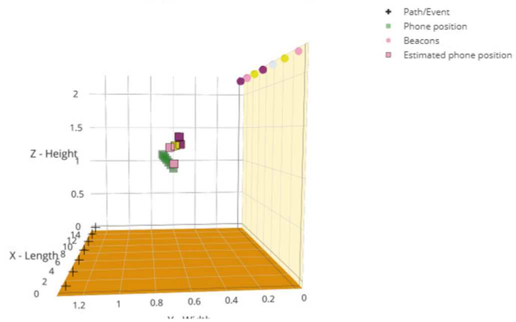
Estimated position of phone
Session: 13-05-18 15:45:10 Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #4

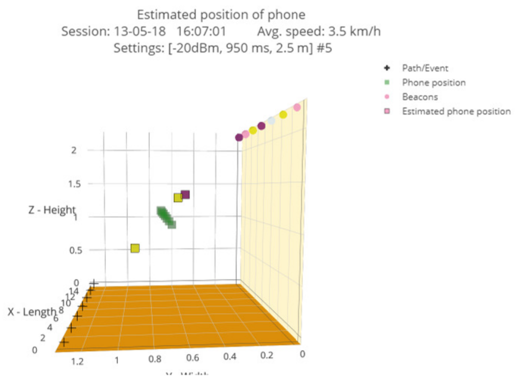


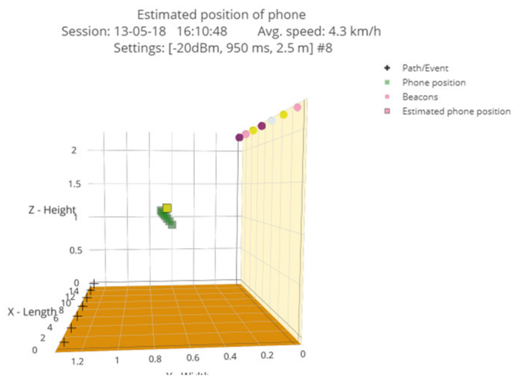
Estimated position of phone
Session: 13-05-18 15:48:43 Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #7

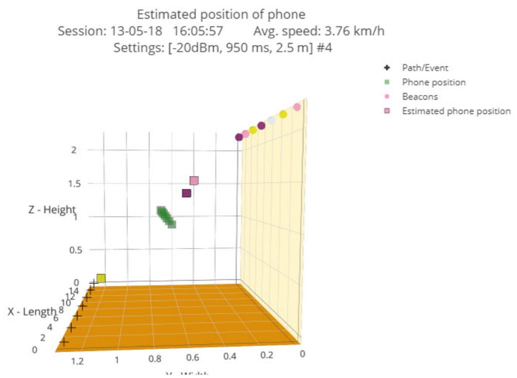


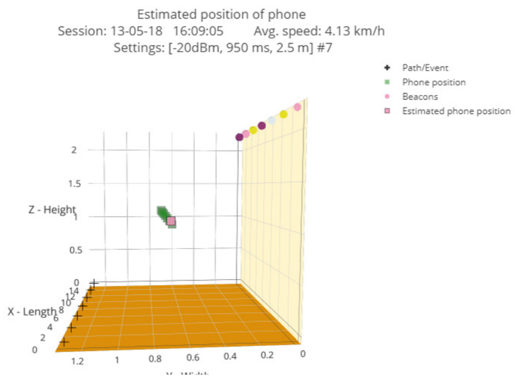
Estimated position of phone
Session: 13-05-18 15:52:55 Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #10

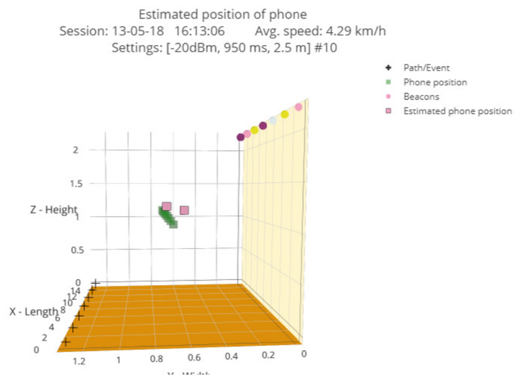


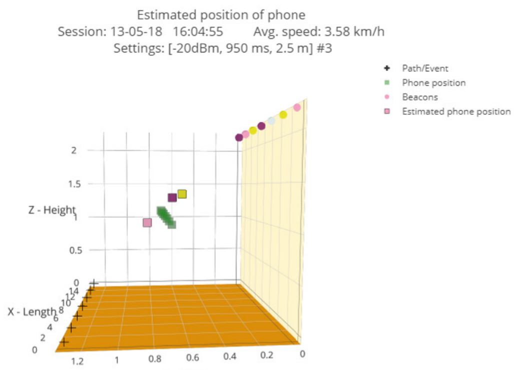

Estimated position of phone
Session: 13-05-18 16:07:01 Avg. speed: 3.5 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #5
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

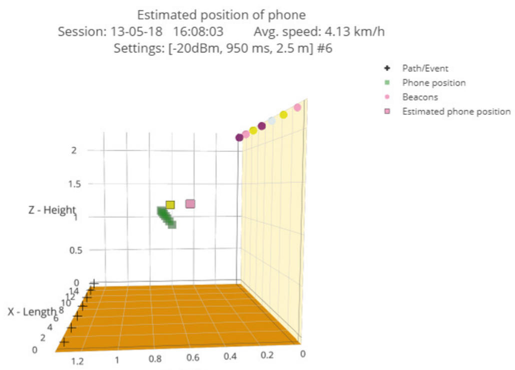

Estimated position of phone
Session: 13-05-18 16:10:48 Avg. speed: 4.3 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #8
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

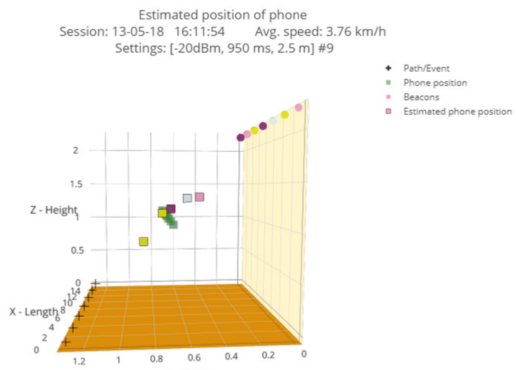

Estimated position of phone
Session: 13-05-18 16:05:57 Avg. speed: 3.76 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #4
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 16:09:05 Avg. speed: 4.13 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #7
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 16:13:06 Avg. speed: 4.29 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #10
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 16:04:55 Avg. speed: 3.58 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #3
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

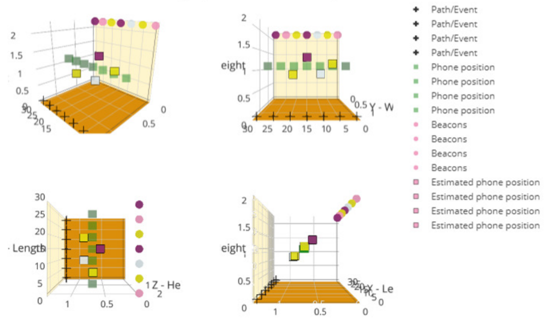

Estimated position of phone
Session: 13-05-18 16:08:03 Avg. speed: 4.13 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #6
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length


Estimated position of phone
Session: 13-05-18 16:11:54 Avg. speed: 3.76 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #9
Path/Event
Phone position
Beacons
Estimated phone position
Z - Height
X - Length

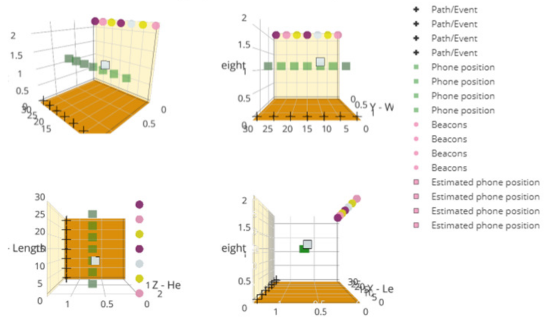
11.1.4 Estimated phone position 3D-graphs with different viewpoints

The attachment is on the next page(s).

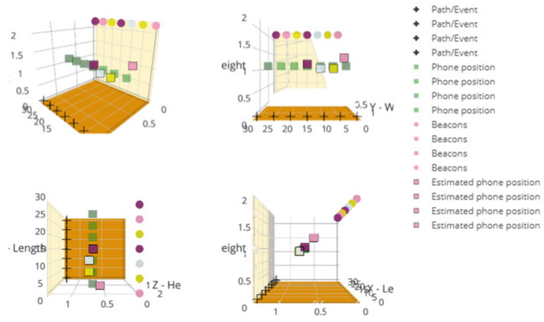
3D Session from different angles, Estimated position of phone
Session: 13-05-18 12:38:43 Avg. speed: 4.49 km/h
Settings: [-20dBm, 950 ms, 5 m] #3



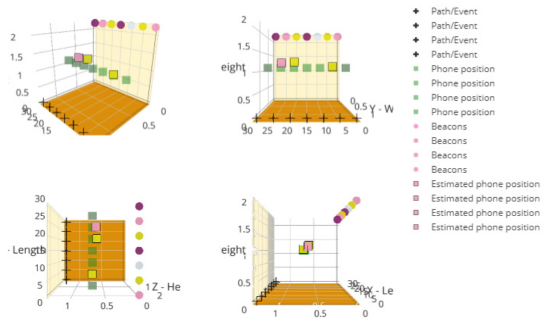
3D Session from different angles, Estimated position of phone
Session: 13-05-18 12:43:58 Avg. speed: 4.23 km/h
Settings: [-20dBm, 950 ms, 5 m] #6



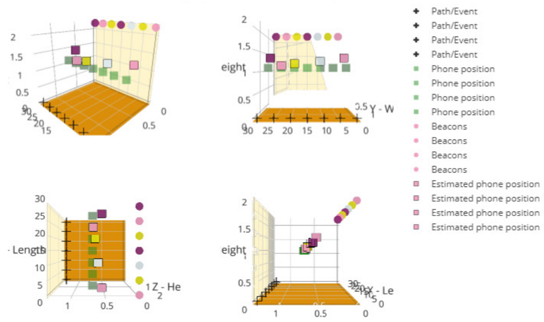
3D Session from different angles, Estimated position of phone
Session: 13-05-18 12:47:58 Avg. speed: 5.02 km/h
Settings: [-20dBm, 950 ms, 5 m] #9



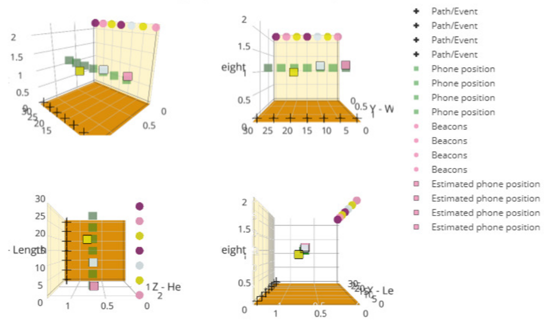
3D Session from different angles, Estimated position of phone
Session: 13-05-18 12:37:22 Avg. speed: 4.42 km/h
Settings: [-20dBm, 950 ms, 5 m] #2



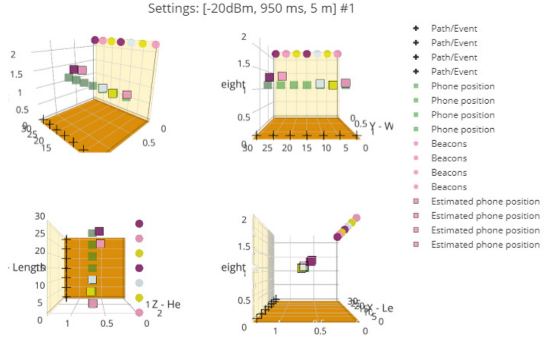
3D Session from different angles, Estimated position of phone
Session: 13-05-18 12:42:33 Avg. speed: 4.55 km/h
Settings: [-20dBm, 950 ms, 5 m] #5



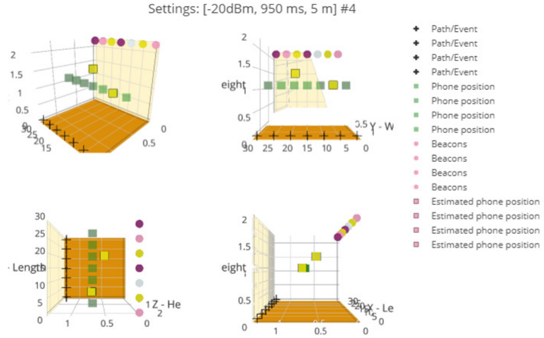
3D Session from different angles, Estimated position of phone
Session: 13-05-18 12:46:35 Avg. speed: 4.08 km/h
Settings: [-20dBm, 950 ms, 5 m] #8



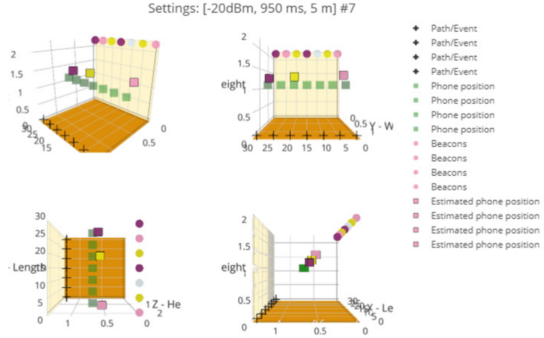
3D Session from different angles, Estimated position of phone
Session: 13-05-18 12:36:04 Avg. speed: 3.88 km/h
Settings: [-20dBm, 950 ms, 5 m] #1



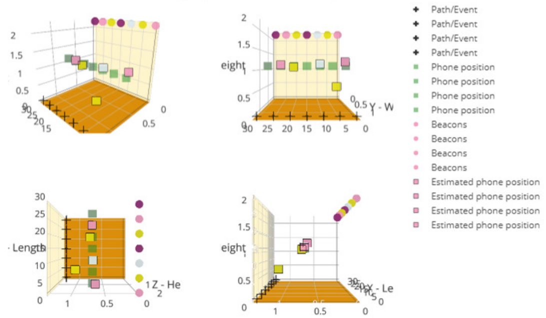
3D Session from different angles, Estimated position of phone
Session: 13-05-18 12:41:12 Avg. speed: 5.11 km/h
Settings: [-20dBm, 950 ms, 5 m] #4



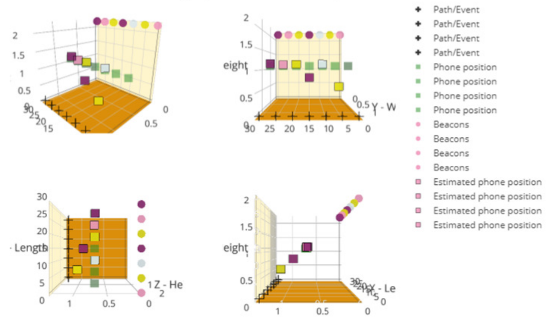
3D Session from different angles, Estimated position of phone
Session: 13-05-18 12:45:17 Avg. speed: 4.55 km/h
Settings: [-20dBm, 950 ms, 5 m] #7



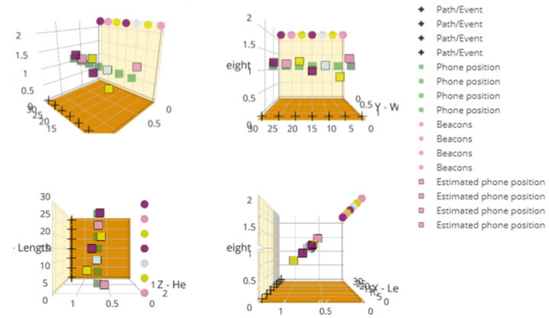
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:00:34 Avg. speed: 4.61 km/h
Settings: [-20dBm, 100 ms, 5 m] #2



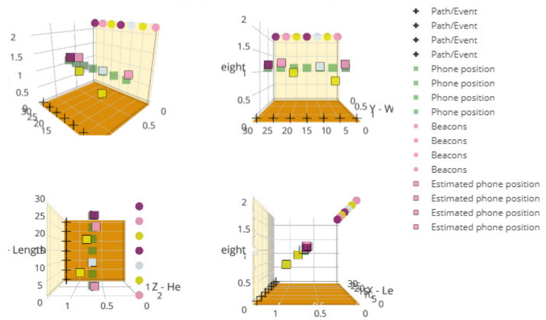
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:05:36 Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 5 m] #5



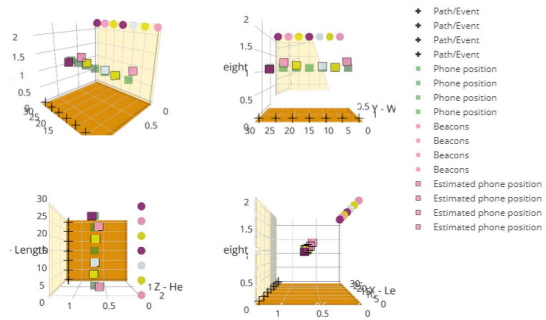
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:09:30 Avg. speed: 4.67 km/h
Settings: [-20dBm, 100 ms, 5 m] #8



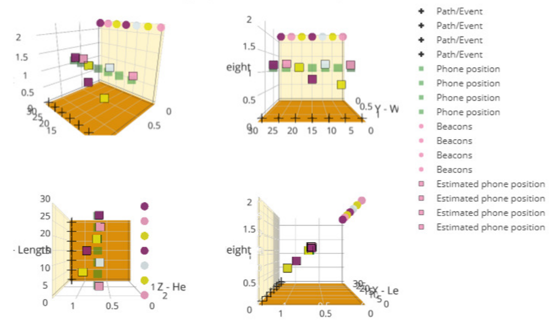
3D Session from different angles, Estimated position of phone
Session: 13-05-18 12:58:57 Avg. speed: 4.73 km/h
Settings: [-20dBm, 100 ms, 5 m] #1



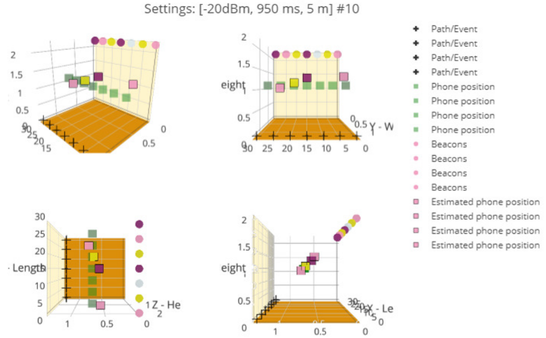
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:03:13 Avg. speed: 4.42 km/h
Settings: [-20dBm, 100 ms, 5 m] #4



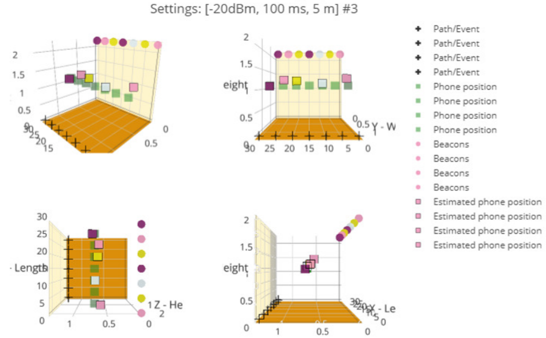
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:08:11 Avg. speed: 4.42 km/h
Settings: [-20dBm, 100 ms, 5 m] #7



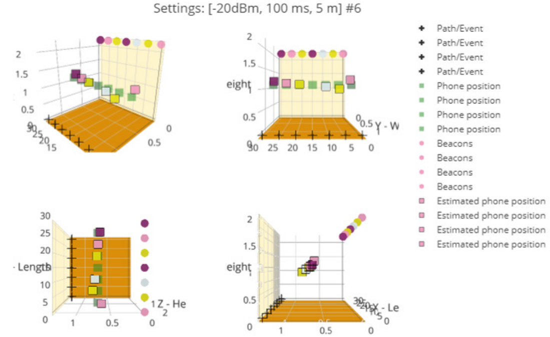
3D Session from different angles, Estimated position of phone
Session: 13-05-18 12:49:22 Avg. speed: 4.61 km/h
Settings: [-20dBm, 950 ms, 5 m] #10



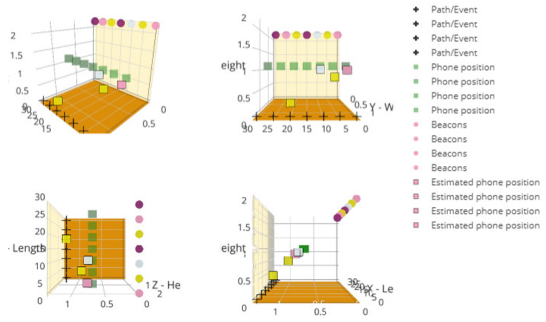
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:01:54 Avg. speed: 4.86 km/h
Settings: [-20dBm, 100 ms, 5 m] #3



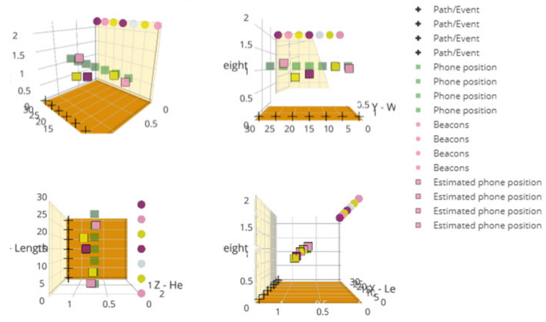
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:06:53 Avg. speed: 4.48 km/h
Settings: [-20dBm, 100 ms, 5 m] #6



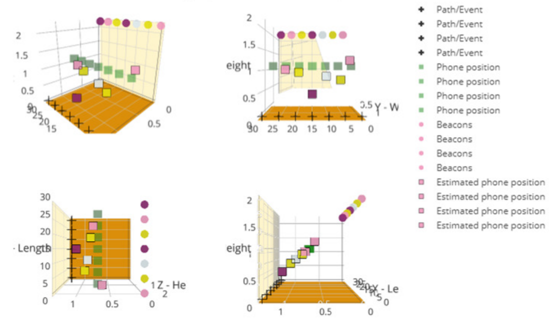
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:31:56 Avg. speed: 4.85 km/h
Settings: [-16dBm, 100 ms, 5 m] #1



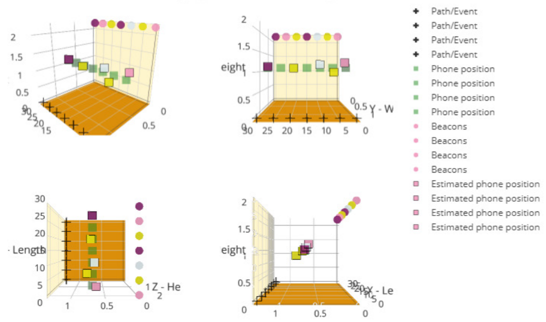
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:36:46 Avg. speed: 4.61 km/h
Settings: [-16dBm, 100 ms, 5 m] #4



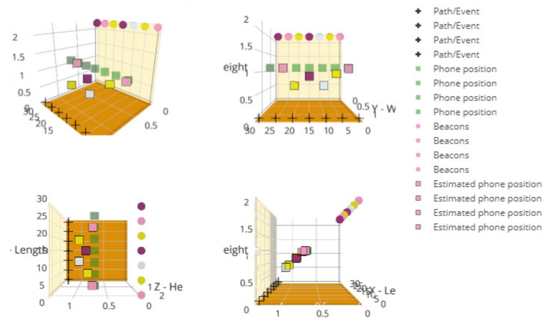
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:41:23 Avg. speed: 4.48 km/h
Settings: [-16dBm, 100 ms, 5 m] #7



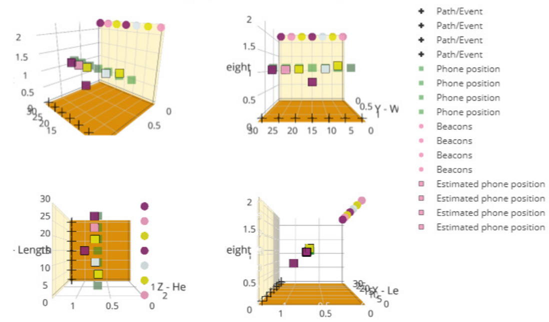
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:12:05 Avg. speed: 4.54 km/h
Settings: [-20dBm, 100 ms, 5 m] #10



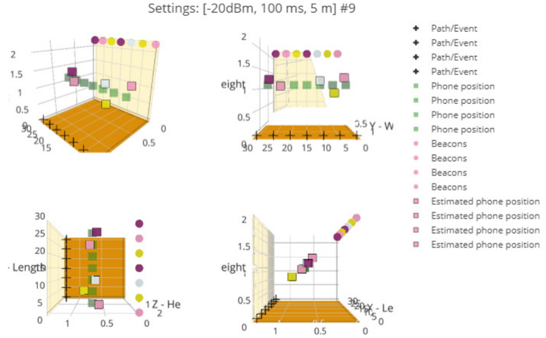
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:34:51 Avg. speed: 4.86 km/h
Settings: [-16dBm, 100 ms, 5 m] #3



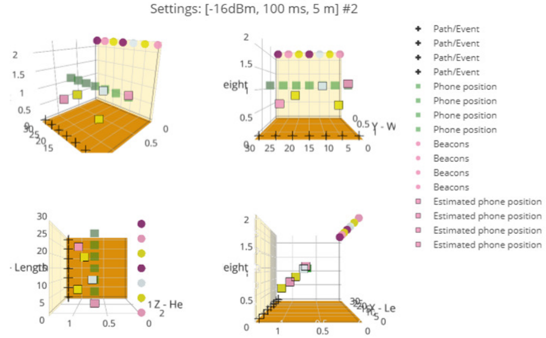
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:40:08 Avg. speed: 4.28 km/h
Settings: [-16dBm, 100 ms, 5 m] #6



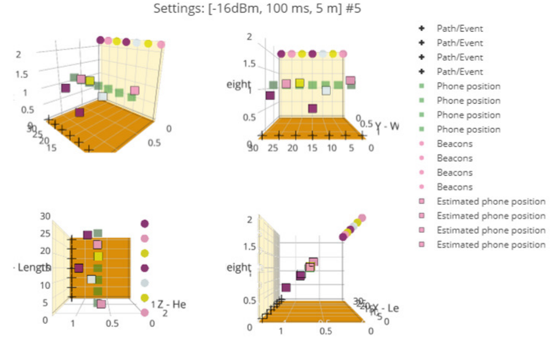
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:10:48 Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 5 m] #9



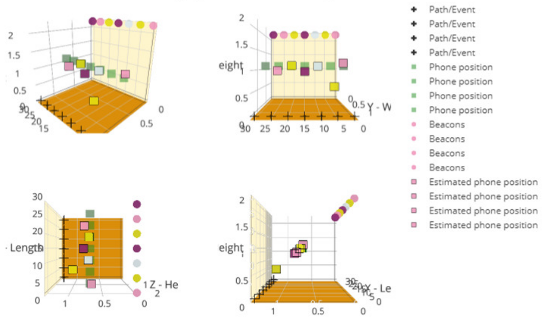
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:33:18 Avg. speed: 5.06 km/h
Settings: [-16dBm, 100 ms, 5 m] #2



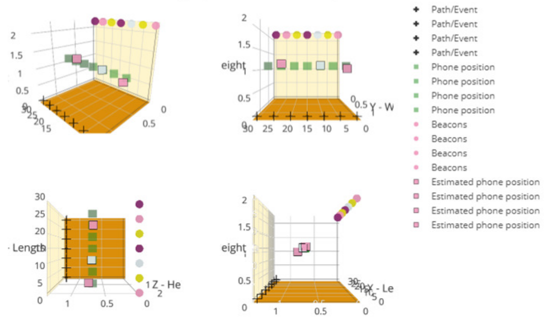
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:38:04 Avg. speed: 4.67 km/h
Settings: [-16dBm, 100 ms, 5 m] #5



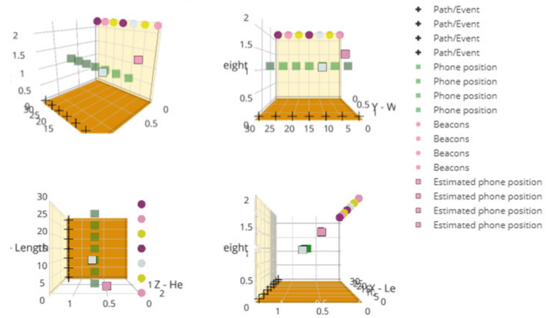
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:45:20 Avg. speed: 4.54 km/h
Settings: [-16dBm, 100 ms, 5 m] #10



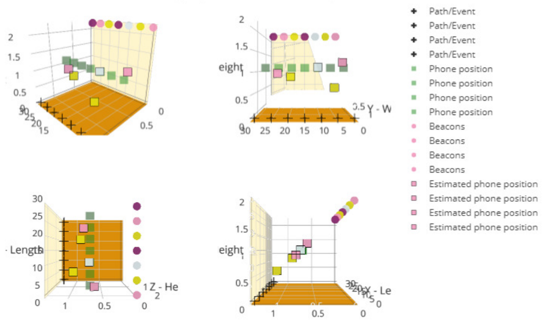
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:56:15 Avg. speed: 4.41 km/h
Settings: [-16dBm, 950 ms, 5 m] #3



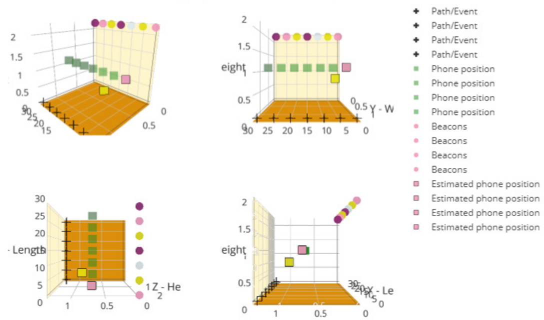
3D Session from different angles, Estimated position of phone
Session: 13-05-18 14:00:18 Avg. speed: 4.42 km/h
Settings: [-16dBm, 950 ms, 5 m] #6



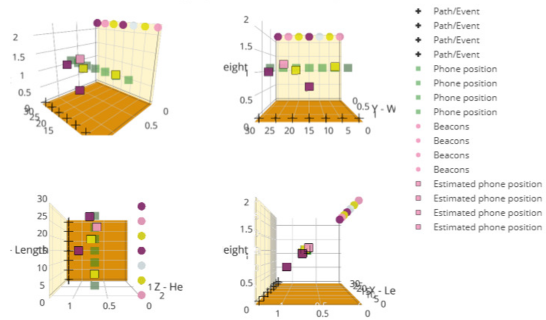
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:44:04 Avg. speed: 4.8 km/h
Settings: [-16dBm, 100 ms, 5 m] #9



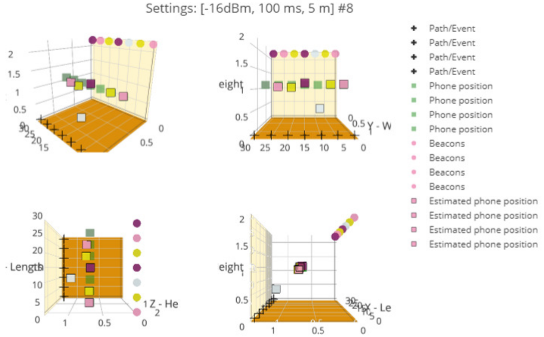
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:54:53 Avg. speed: 4.74 km/h
Settings: [-16dBm, 950 ms, 5 m] #2



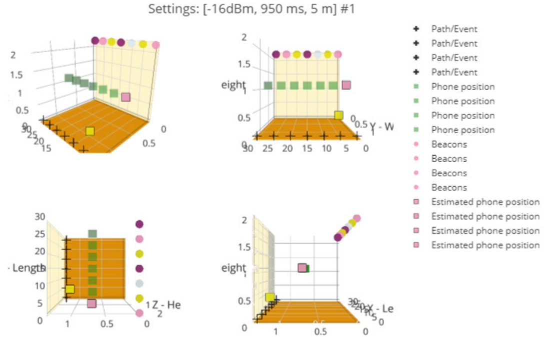
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:59:00 Avg. speed: 4.74 km/h
Settings: [-16dBm, 950 ms, 5 m] #5



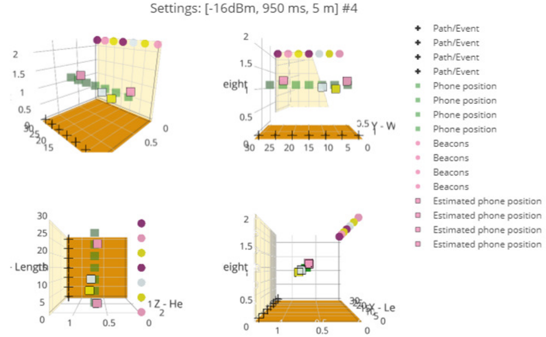
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:42:38 Avg. speed: 4.54 km/h
Settings: [-16dBm, 100 ms, 5 m] #8



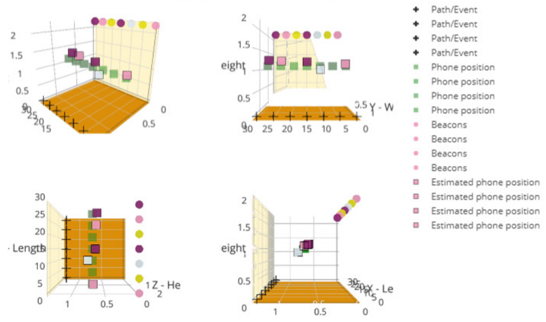
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:53:32 Avg. speed: 4.16 km/h
Settings: [-16dBm, 950 ms, 5 m] #1



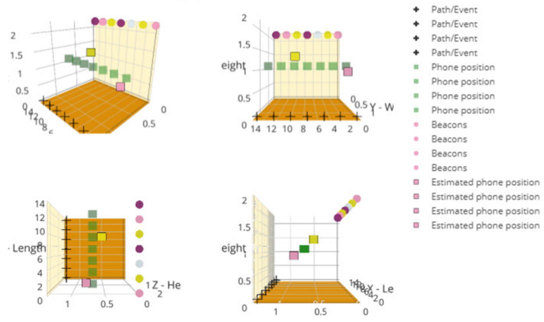
3D Session from different angles, Estimated position of phone
Session: 13-05-18 13:57:43 Avg. speed: 4.92 km/h
Settings: [-16dBm, 950 ms, 5 m] #4



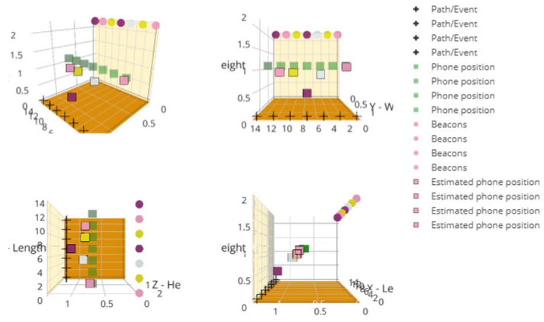
3D Session from different angles, Estimated position of phone
Session: 13-05-18 14:04:30 Avg. speed: 4.3 km/h
Settings: [-16dBm, 950 ms, 5 m] #9



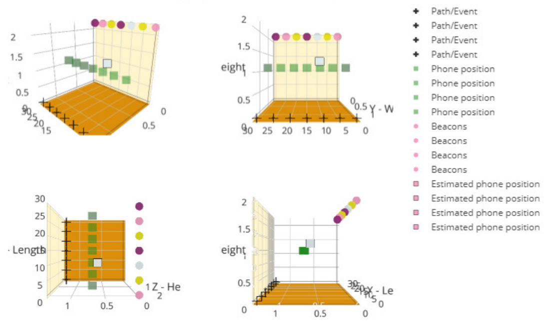
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:08:01 Avg. speed: 5.01 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #2



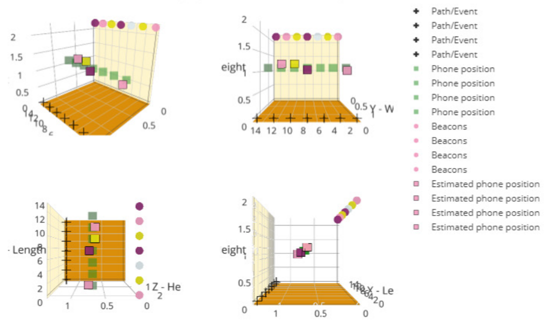
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:11:43 Avg. speed: 4.91 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #5



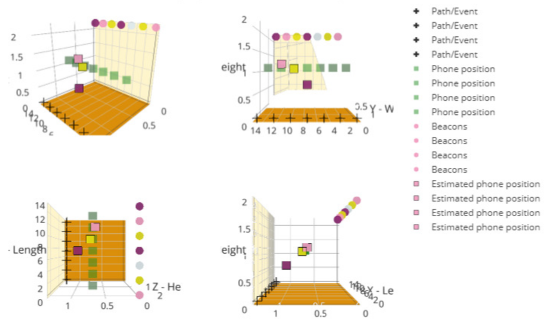
3D Session from different angles, Estimated position of phone
Session: 13-05-18 14:03:11 Avg. speed: 4.29 km/h
Settings: [-16dBm, 950 ms, 5 m] #8



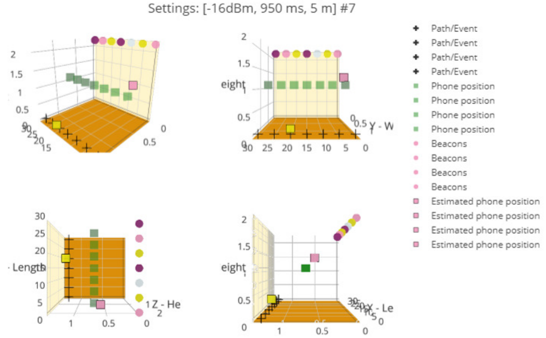
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:06:53 Avg. speed: 4.09 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #1



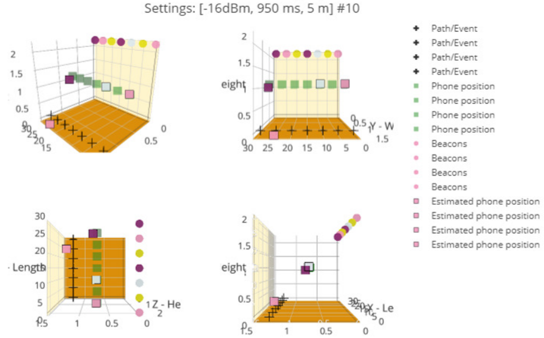
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:10:11 Avg. speed: 4.83 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #4



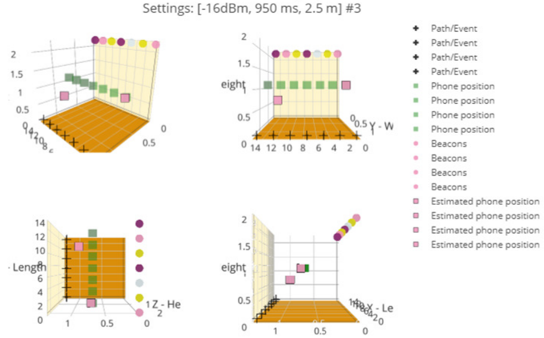
3D Session from different angles, Estimated position of phone
Session: 13-05-18 14:01:36 Avg. speed: 4.54 km/h
Settings: [-16dBm, 950 ms, 5 m] #7



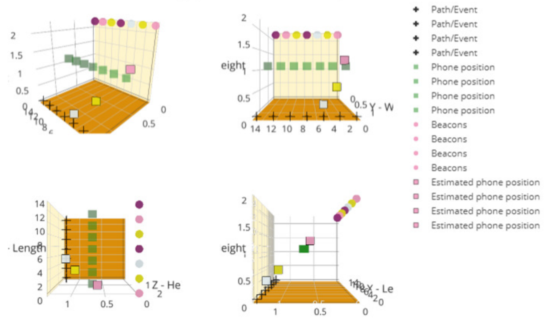
3D Session from different angles, Estimated position of phone
Session: 13-05-18 14:05:48 Avg. speed: 4.15 km/h
Settings: [-16dBm, 950 ms, 5 m] #10



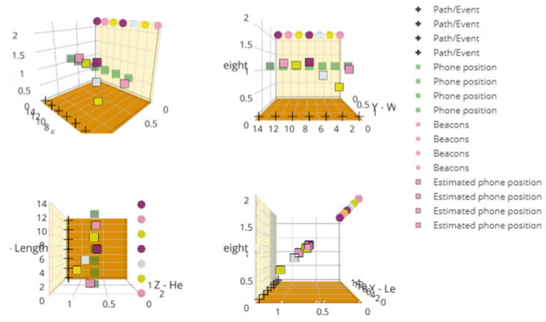
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:09:06 Avg. speed: 4.92 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #3



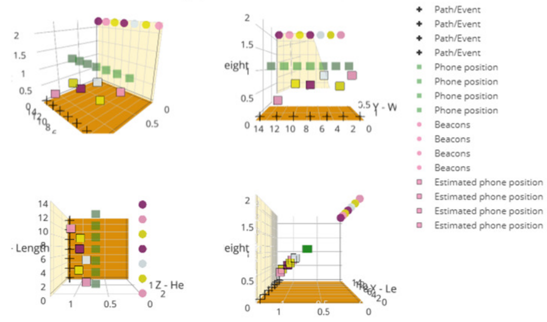
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:15:02 Avg. speed: 3.49 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #8



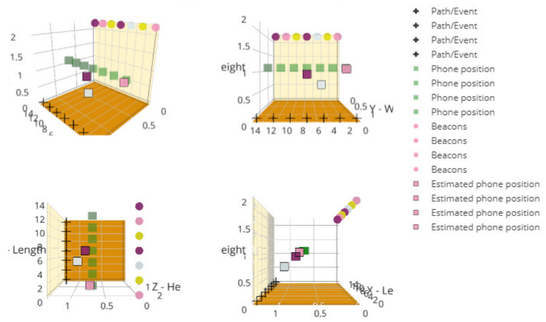
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:24:02 Avg. speed: 3.6 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #1



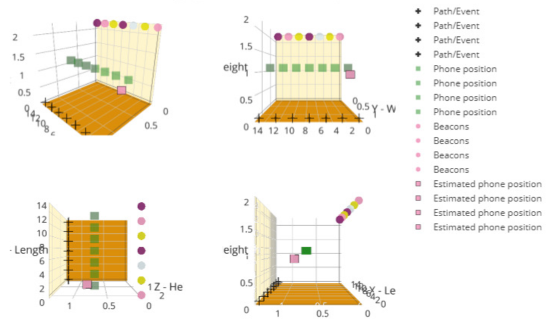
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:27:51 Avg. speed: 3.92 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #4



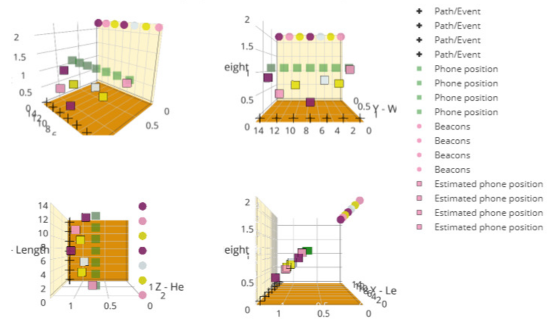
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:13:55 Avg. speed: 4.24 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #7



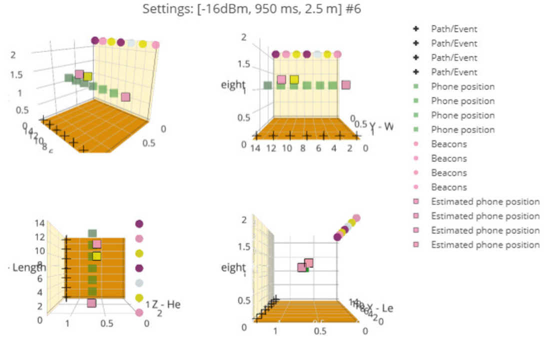
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:17:16 Avg. speed: 3.99 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #10



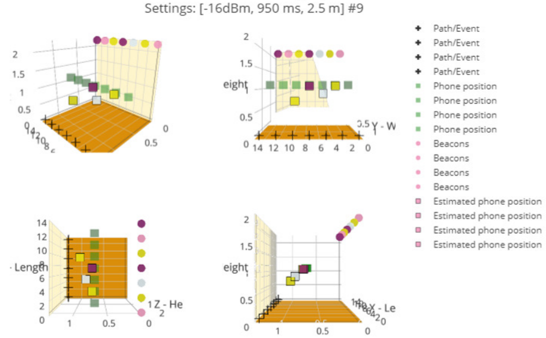
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:26:46 Avg. speed: 3.84 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #3



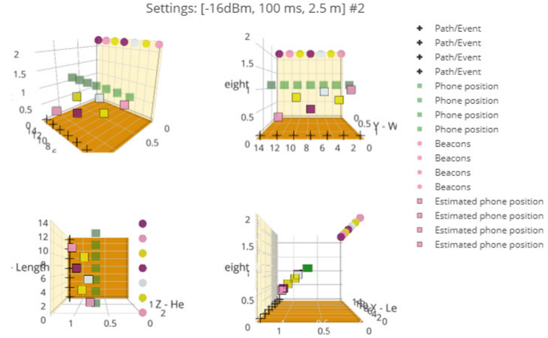
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:12:51 Avg. speed: 3.57 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #6



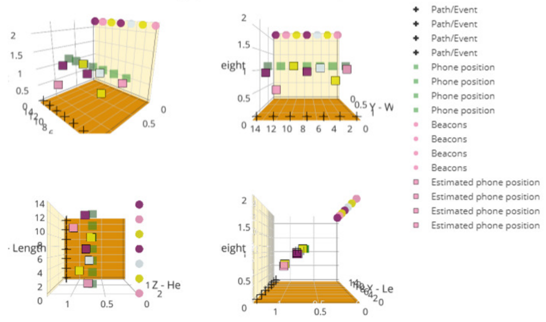
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:16:10 Avg. speed: 4.16 km/h
Settings: [-16dBm, 950 ms, 2.5 m] #9



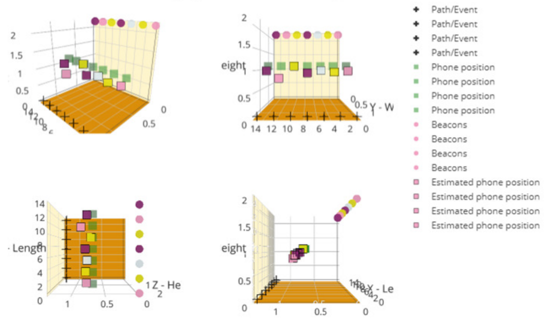
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:25:21 Avg. speed: 3.56 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #2



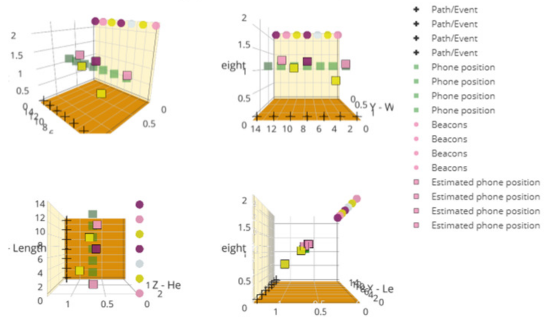
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:31:06 Avg. speed: 3.92 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #7



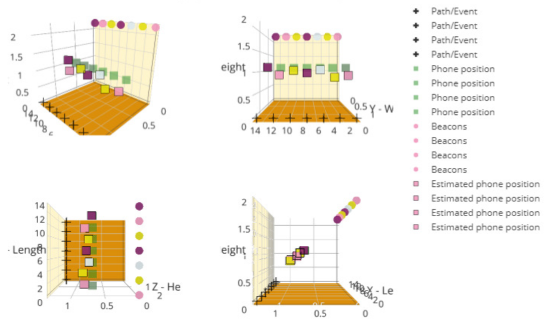
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:34:19 Avg. speed: 3.73 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #10



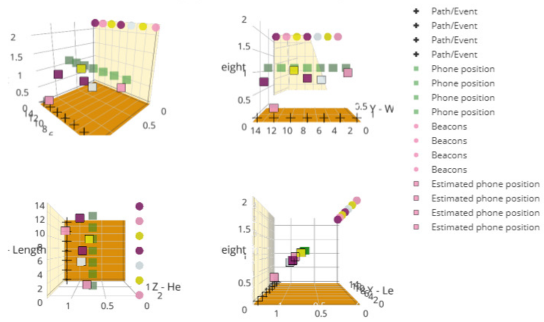
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:44:04 Avg. speed: 3.84 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #3



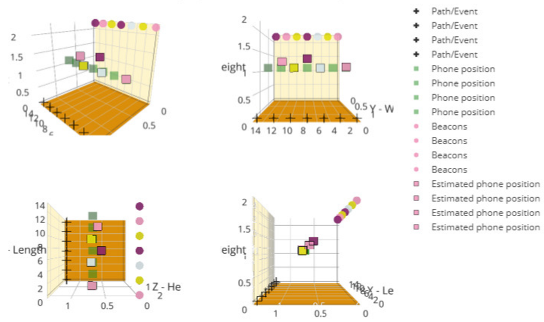
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:30:02 Avg. speed: 3.99 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #6



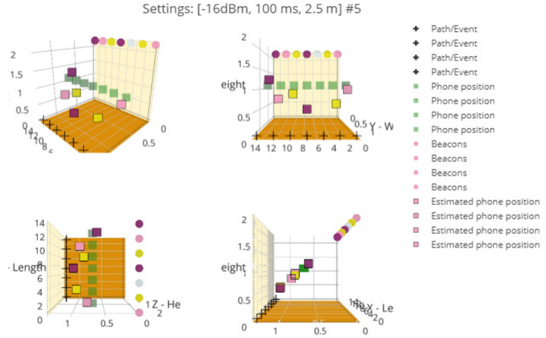
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:33:16 Avg. speed: 4.13 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #9



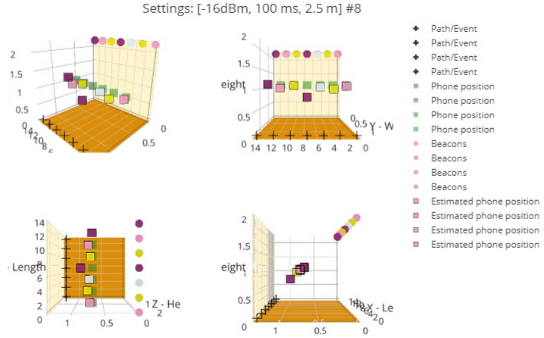
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:43:01 Avg. speed: 3.5 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #2



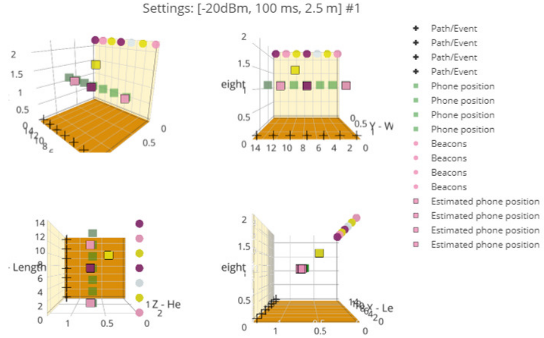
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:28:55 Avg. speed: 4.45 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #5



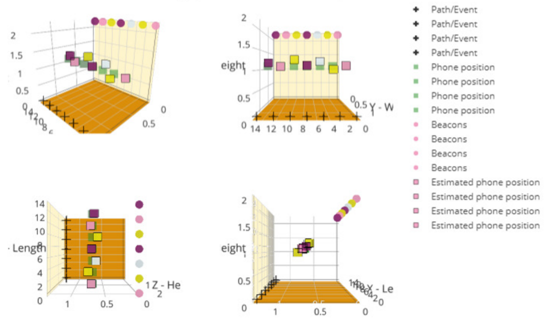
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:32:12 Avg. speed: 4.21 km/h
Settings: [-16dBm, 100 ms, 2.5 m] #8



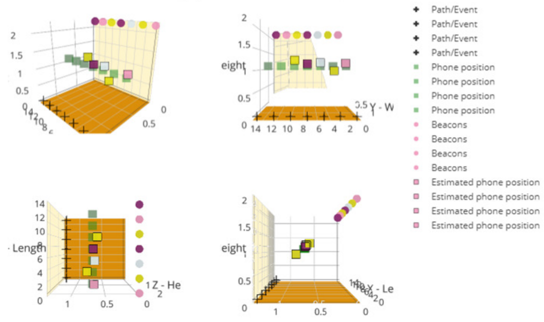
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:41:54 Avg. speed: 3.3 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #1



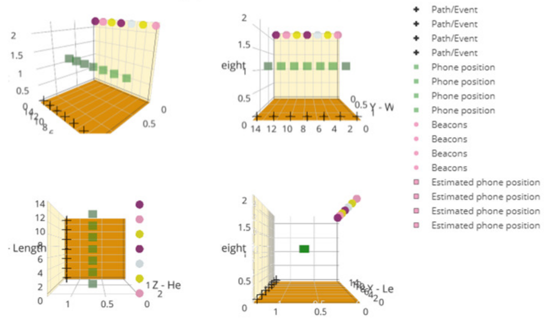
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:47:41 Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #6



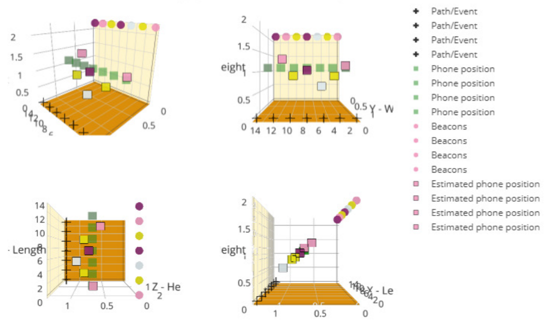
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:51:38 Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #9



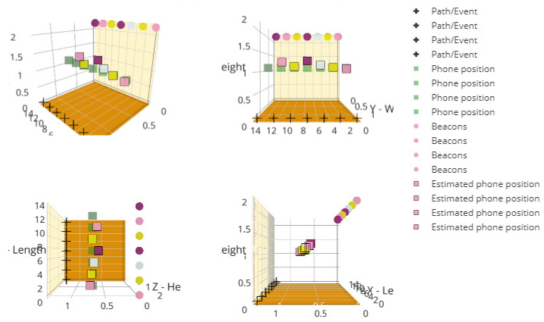
3D Session from different angles, Estimated position of phone
Session: 13-05-18 16:03:51 Avg. speed: 4.15 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #2



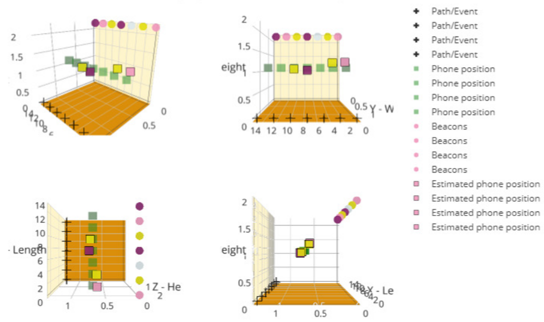
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:46:14 Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #5



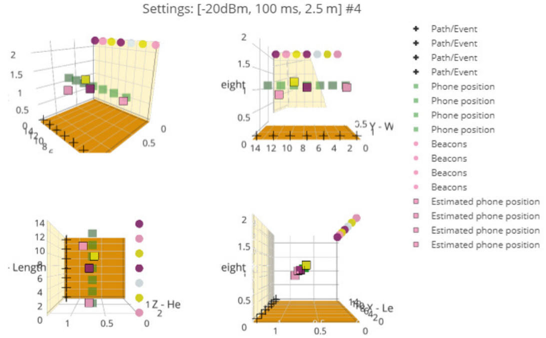
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:50:36 Avg. speed: 4.03 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #8



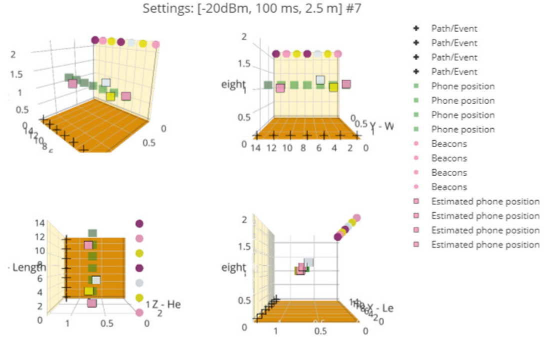
3D Session from different angles, Estimated position of phone
Session: 13-05-18 16:02:43 Avg. speed: 3.89 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #1



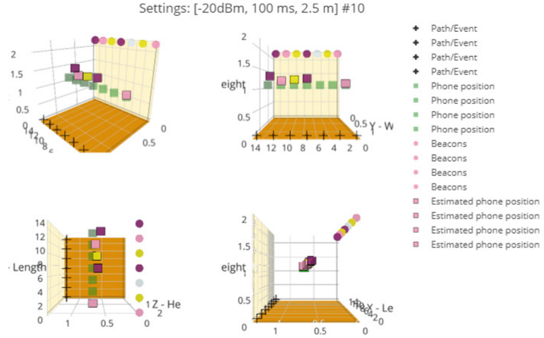
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:45:10 Avg. speed: 3.97 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #4



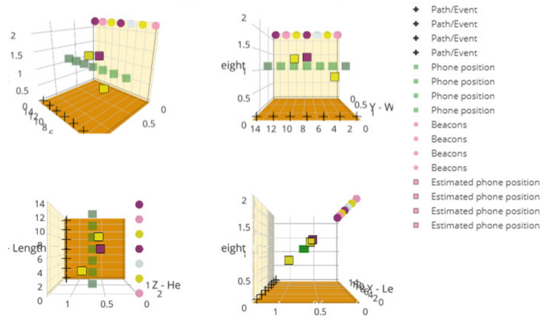
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:48:43 Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #7



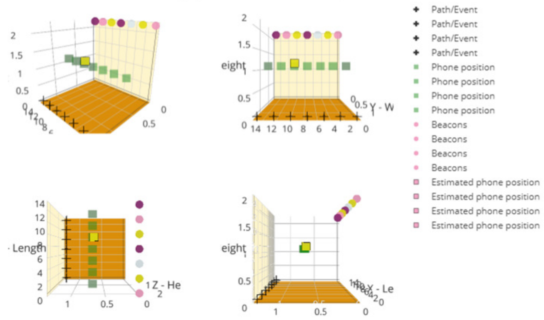
3D Session from different angles, Estimated position of phone
Session: 13-05-18 15:52:55 Avg. speed: 4.21 km/h
Settings: [-20dBm, 100 ms, 2.5 m] #10



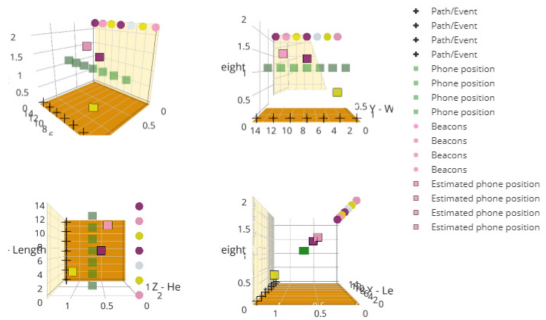
3D Session from different angles, Estimated position of phone
Session: 13-05-18 16:07:01 Avg. speed: 3.5 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #5



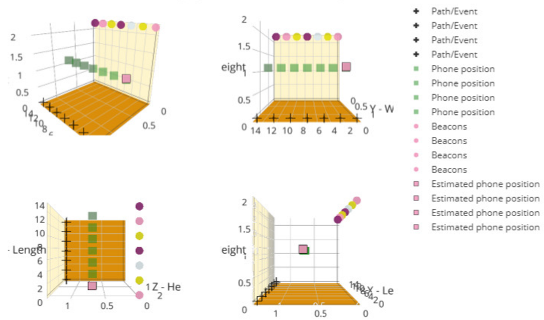
3D Session from different angles, Estimated position of phone
Session: 13-05-18 16:10:48 Avg. speed: 4.3 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #8



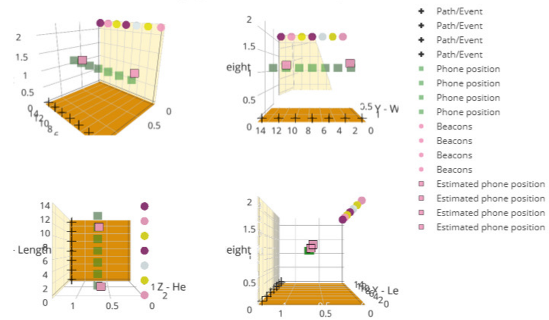
3D Session from different angles, Estimated position of phone
Session: 13-05-18 16:05:57 Avg. speed: 3.76 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #4



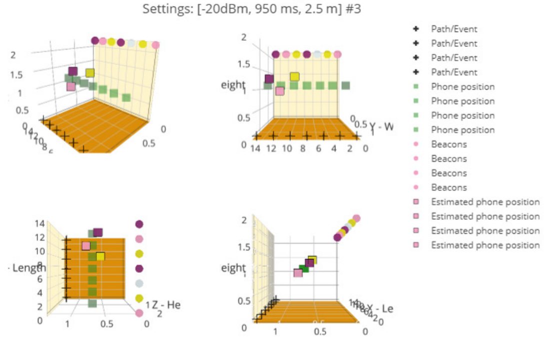
3D Session from different angles, Estimated position of phone
Session: 13-05-18 16:09:05 Avg. speed: 4.13 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #7



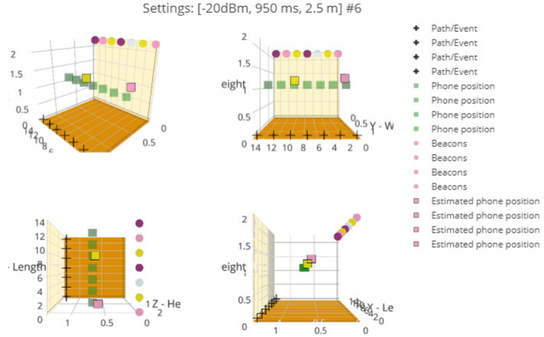
3D Session from different angles, Estimated position of phone
Session: 13-05-18 16:13:06 Avg. speed: 4.29 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #10



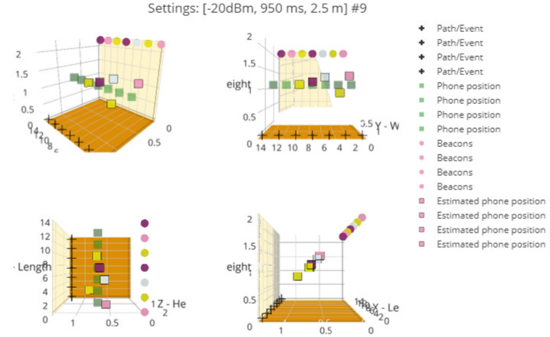
3D Session from different angles, Estimated position of phone
Session: 13-05-18 16:04:55 Avg. speed: 3.58 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #3



3D Session from different angles, Estimated position of phone
Session: 13-05-18 16:08:03 Avg. speed: 4.13 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #6



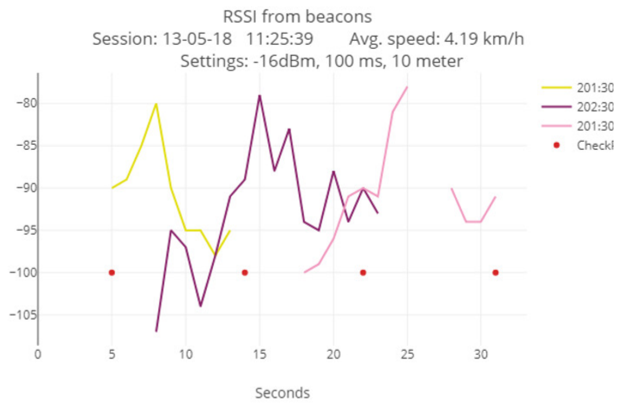
3D Session from different angles, Estimated position of phone
Session: 13-05-18 16:11:54 Avg. speed: 3.76 km/h
Settings: [-20dBm, 950 ms, 2.5 m] #9



11.1.5 Predecessor comparability testing graphs

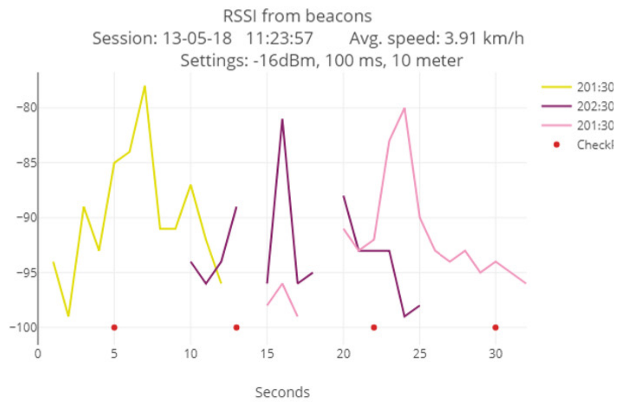
The attachment is on the next page(s).

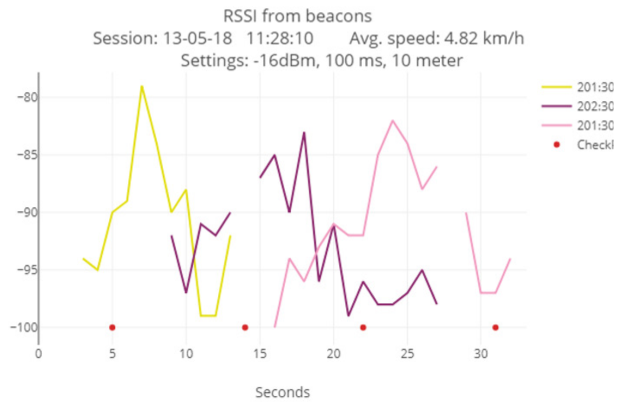

RSSI from beacons
Session: 13-05-18 11:21:31 Avg. speed: 4.47 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl


RSSI from beacons
Session: 13-05-18 11:25:39 Avg. speed: 4.19 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl


RSSI from beacons
Session: 13-05-18 11:29:25 Avg. speed: 3.84 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl

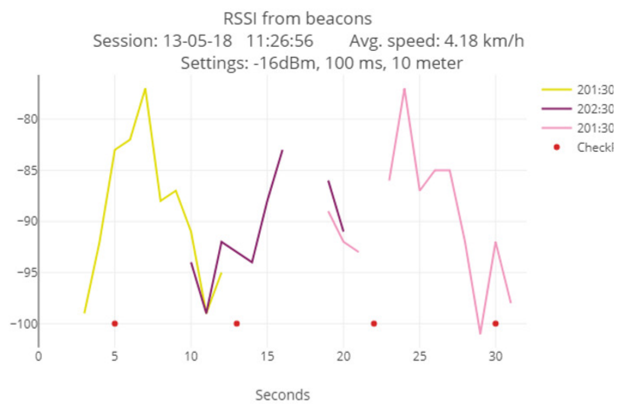

RSSI from beacons
Session: 13-05-18 11:20:11 Avg. speed: 4.54 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl


RSSI from beacons
Session: 13-05-18 11:23:57 Avg. speed: 3.91 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl

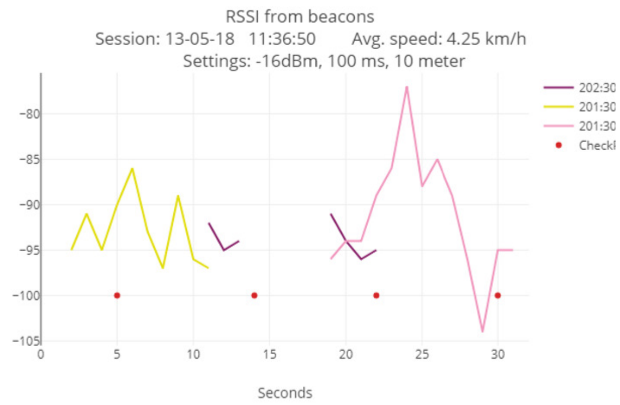

RSSI from beacons
Session: 13-05-18 11:28:10 Avg. speed: 4.82 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl

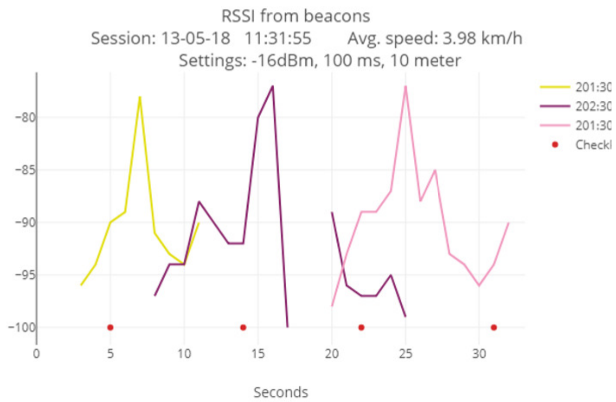

RSSI from beacons
Session: 13-05-18 11:18:48 Avg. speed: 4.68 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl

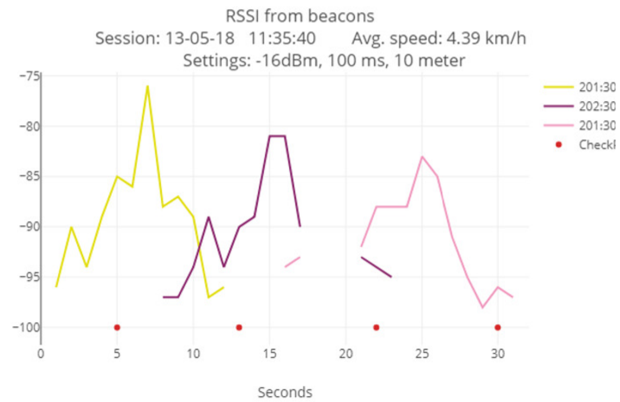

RSSI from beacons
Session: 13-05-18 11:22:46 Avg. speed: 4.46 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl

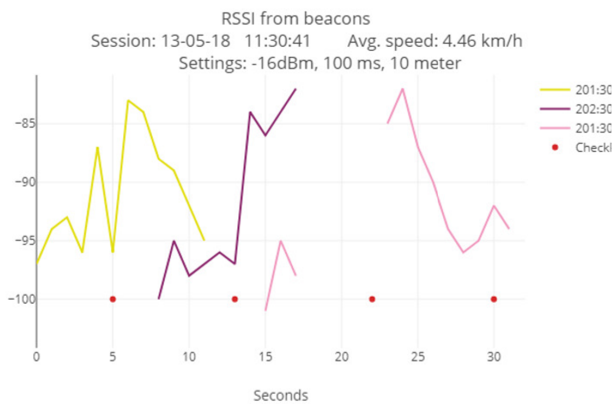

RSSI from beacons
Session: 13-05-18 11:26:56 Avg. speed: 4.18 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl


RSSI from beacons
Session: 13-05-18 11:33:08 Avg. speed: 4.54 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl


RSSI from beacons
Session: 13-05-18 11:36:50 Avg. speed: 4.25 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
202:30
201:30
201:30
Checkl


RSSI from beacons
Session: 13-05-18 11:31:55 Avg. speed: 3.98 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl


RSSI from beacons
Session: 13-05-18 11:35:40 Avg. speed: 4.39 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl


RSSI from beacons
Session: 13-05-18 11:30:41 Avg. speed: 4.46 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl


RSSI from beacons
Session: 13-05-18 11:34:21 Avg. speed: 4.9 km/h
Settings: -16dBm, 100 ms, 10 meter
Seconds
201:30
202:30
201:30
Checkl