Santiago Torres

Indoor Positioning Using Bluetooth Low Energy Beacons

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PREFACE

The study henceforth presented was conducted by the author, Santiago Torres, for the Finnish company Kassamagneetti.

One of the biggest challenges during the competition of this research was to realise when to move away from the chosen hardware because of lack of support from the manufacturers and software company behind the product. This lack of support caused weeks of delay in the testing and wasted time away from the research. In the bright side, there was a good lesson learned about what to look for when investing in hardware components.

I would like to thank Kassamagneetti and specially to Mats Antell, Priit Karu, and Fredrik Blummé for the opportunity. Also, I would like to thank Sonja Holappa, Annamari Nevala, Aleksandra Reskalenko, Ramona Kirves, Karolina Iisssalo, and Tenho Restobar for their help in the competition of this work.

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This thesis was done for the Finnish company Kassamagneetti Oy. The main purpose was to find a way to obtain accurate indoor location using Bluetooth Low Energy (BLE) beacons to be used in the restaurant business.

The company Develops software to be used in point of sale for restaurants and bars among other things.

The intended idea was to develop a self-service system that will allow customers to place an order from a mobile device at any table of the restaurant. Then the device automatically will get the location inside the premises for the staff to find them and deliver the order.

This study found that a beacon network can be used in the restaurant business to accurately find customers on tables after they have placed an order on their mobile devices or a tablet handed out by the restaurant. The test results showed that the best approach to be used is iBeacon proximity framework. Trilateration of a beacon network does not offer the same level of accuracy and adds unnecessary complexity to the system. It can be used as complementary to the proximity.

Key words	Bluetooth, beacon, indoor location, BLE, Bluetooth Low Energy, iBeacon, Radio waves.

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List of Abbreviations

AA	50.5mm x 14.5mm battery
ADV	Advertisement
API	Application Program Interface
ARM	Advanced RISC Machine
BLE	Bluetooth Low Energy
BR	Basic Rate
CLBeacon	Core Location Beacon
CRC	Cyclic Redundancy Check
dBm	Decibel-milliwatts
EDR	Enhanced Data Rate
FCC	Federal Communication Commission
GHz	Giga Hertz
GLONNASS	Global Navigation Satellite System
GPS	Global Positioning System
IOS	Apple's Mobile Operating System
IPS	Indoor Positioning System
IR	Infrared Radiation
ISM	Industrial Scientific Medic
KB	Kilo Bytes
LORAN	Long Range Navigation
LTD	Limited company
M	Meters
MHz	Mega Hertz
MS	Milliseconds
OTP	One Time Programmable

PDU	Protocol Data Unit
RADAR	Radio Detection and Ranging
RAM	Random Access Memory
ROM	Read Only Memory
RSSI	Received Signal Strength Indicator
SDK	Software Development Kit
SMC	Sequential Monte Carlo
SRAM	Static Random Access Memory
Sig ID	Signal Identification
TLM	Telemetry
TX Power	Transmitted power
UK	United Kingdom
URL	Uniform Resource Locator
UUID	Universal Unique Identifier
WIFI	Wireless Fidelity
WLAN	Wireless Local-Area Network

1. INTRODUCTION

This study explores the possibility of using Bluetooth Low Energy beacons for indoor location. Global Positioning System (GPS) is not reliable enough to get an accurate location inside buildings (micro location) due to the GPS accuracy, which gets largely reduced inside buildings. There have been some improvements done to some location services that combine GPS and other radio signals from WIFI networks and Cell towers that help to increase the accuracy indoors or in urban areas where the GPS alone is not accurate.

There are several alternatives to get a more accurate indoor location. This research focuses on the use of BLE Beacons and possible combinations of these with other existing technologies. BLE Beacons are cheap devices that most cases run on small batteries from months to years and broadcast a radio signal using low energy bluetooth 4.0.

During the past years, big companies have been creating standard protocol as a framework to make the technology more accessible for developers to add to applications. The main ones are iBeacon from Apple and EddyStone from Google, and they both work cross-platform. These technologies have different approaches to the information that are broadcasting the beacons. iBeacon uses four parameters in one signal whereas Eddystone uses two different signals to broadcast three parameters of information.

This study also compared the different ways to analyse and combine the signals; by analysing the Received Signal Strength Indicator (RSSI), trilateration fingerprinting and particle filtering to get the intended results.

This thesis was done for Kassamagneetti Oy company. The company offers cash register and software services for restaurants, bars, and other businesses. The company has already developed software to make orders from mobile devices but there is not accurate way to get the location inside the business facilities. The goal is to use Bluetooth low energy beacons for indoor location.

A use case example: a customer places an order within the device and the application using the Bluetooth Low Energy beacons obtains the location of the device and assigns a table to the customer. At the end the staff can deliver the product to the table.

2. A BRIEF HISTORY OF NAVIGATION

Since humans have been around they have been developing tools to help them to navigate around the Earth. Especially at sea, it was more vital to know your way as there is fewer reference points. Some of the earliest methods used by humans were to look at the position of the Sun and the stars in the sky [18]. Carrying animals, commonly birds [30], to use them as means of navigation. After time humans developed more complex tools to improve the reliability and accuracy of the navigation.

2.1. Early Days of Navigation

Cartography is the art and science of drawing maps, the oldest maps preserved are Babylonian clay tablets from about 2300 B.C. [31] But it was not used that much at sea until the half of the thirteenth century when sailors began realising that maps could be of great use and they began keeping detailed records of their travels. And this is how the first nautical charts were created. These first maps were not very reliable, there was no latitude or longitude only marks between ports and a compass rose indicating the direction to travel but were considered valuable [18].

The Mariner's Compass is one of the earliest navigational tools artificially made. It was used to aid navigation at sea and it was a primitive version of the magnetic compass. It was not a perfect tool as it was often inaccurate. At that time there was not understanding the concept of magnetic variation, which is the difference between geographic north and magnetic north. The main purpose they used was to identify the direction from which the wind was blowing and when the Sun was not visible [18].

During the fifteen hundreds, the chip log was invented; it consisted of line with knots at regular intervals and weighted to drag in the water. It was used as a way to calculate the ship's speed by letting out over the stern the weight as the ship was underway. And a seaman would count the number of knots that went pulled out over a specific period of time [18].

Sailors used other instruments to help them determining the latitude, these were the astrolabe and quadrant. The astrolabe was an ancient Greece invention; Then it was used by astronomers. But it was only used by sailors in the late fifteenth century by measuring the altitude of the Sun and stars [18].

John Hadley (1682–1744) was an English mathematician, and Thomas Godfrey (1704–1749) was an American inventor, that around 1730, both independently invented the sextant. The sextant gave sailors the ability of accurately determining the angle between the Sun, moon or stars with the horizon, in order to calculate latitude [18].

There was a limitation with these methods as only help to calculate the latitude. Sailors had to guess the longitude; To calculate it they needed to compare the time and position of the Sun between two places, therefore to have an accurate clock was of vital importance as 10 minutes per day, which translated into a computational error of 242 kilometres or more, which was a common error in the best clocks of early eighteenth century [18]

In 1764, John Harrison (1693–1776) a British clockmaker invented the seagoing chronometer. This invention supposed the most important advance to marine navigation to its date. In 1779, British naval officer and explorer Captain James Cook (1728–1779) used Harrison's chronometer to circumnavigate the globe. When he returned, his calculations of longitude using the chronometer proved correct to within 13 kilometres [18].

2.2. Modern Day Navigation Systems

In the twentieth century, important advances were made for marine navigation with radio beacons, radar, the gyroscopic compass and the Global Positioning System (GPS). Most oceangoing vessels keep a sextant on board only in the case of an emergency.

The gyroscopic compass was introduced in 1907. The primary benefit of the gyroscopic compass over a magnetic compass is that this is unaffected by the Earth's or the ship's magnetic field and always points to geographic north [18].

The first practical RADAR (radio detection and ranging) was made by Christian Hülsmeyer, who demonstrated the effectiveness of the system in 1904 [32]. It was used to locate other boats hundreds of meters away by projecting radio waves against them [33]. This was, and still is, very useful on ships today.

In the early ‘40s the ground-based hyperbolic radio navigation systems were developed. The British Gee was the first one, used to cover from England to Germany, and it was followed by the U.S. navigation system known as Long Range Navigation (LORAN) that covered the Atlantic ocean. They use pulsed radio transmissions from so-called "master" and "slave" stations to determine a ship's or plane's position. The accuracy of this system is measured in hundreds of meters and has limited coverage [34]. Decca navigation system was also developed in this period but it used phase comparison of two low frequency signals and this made it easier to implement the receiver [35]. This kind of navigation system became obsolete in the ‘90s and was replaced by the Global Positioning System.

Global Positioning System (GPS) is the first of the satellite navigation system. It was launched in the early 1970s by the United States and became fully operational in 1993. For the system to work globally a receiver needs to be in contact with at least four satellites. For this reason, the system requires at least 24 satellites in orbit. The figure 1 shows how the satellite constellation works to always have at least 4 satellites visible at any point of the globe.

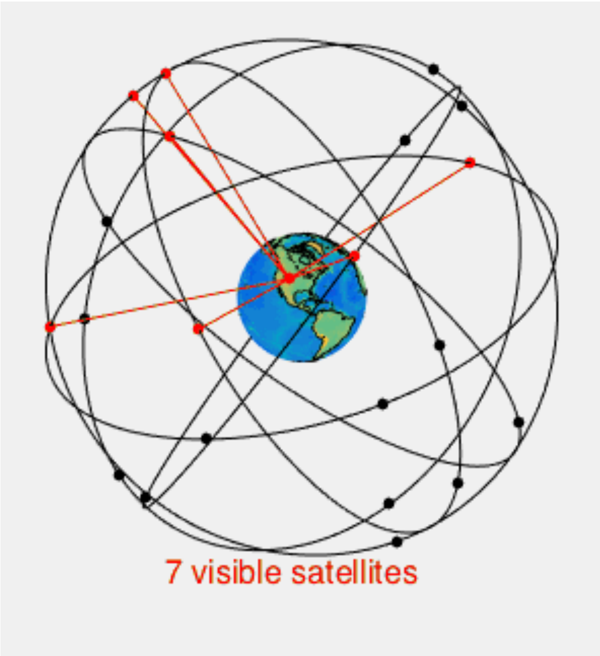

Figure 1. Representation of GPS satellite constellation.

Of course, the more satellites the faster and more accurate a position can be rendered. GPS works based on radio waves, time and the known position of GPS satellites. The satellites are loaded with very accurate atomic clocks that are synchronised across the system. Every day there are time changes, due to the effects of relativity, therefore corrections need to be made on the ground to compensate for the discrepancy. The satellite locations are known with great precision. GPS receivers have clocks as well, but they do not need to be as precise as the satellite ones. Each GPS satellite continuously transmits a radio signal containing the current time and data about its position. Since the speed of radio waves is constant and independent of the satellite speed, the time of flight can be measured and with that the location of the receiver. At a minimum, four satellites must be in view of the receiver for it to compute the four unknown quantities, three spatial coordinates and time deviation from the satellites [36,37,38].

GPS is not the only satellite navigation system but because it was created by the United States, they have control over it. Some other countries have developed their own to avoid dependency on the United States. Russia has GLONASS and the European Union have Galileo which is expected to be fully functional by 2020. China and India are also developing their own systems [37].

Global Satellite location systems are the best tools for getting an accurate location anywhere in the world, especially with the combination of several satellite constellations. But this technology is not that reliable to obtain a precise location indoors because of the presence of obstacles, in the line of sight between the satellite and the receiver spread and attenuate the electromagnetic waves.

2.3. Indoor Navigation Systems

To overcome the GPS limitations on indoor location, another indoor positioning system (IPS) technologies have been used to obtain greater accuracy indoors. Some of them are overviewed bellow.

One of them is Infrared radiation (IR) positioning systems. The infrared region of the spectrum has been used in various ways for detection or tracking of objects or persons. Most IR based wireless devices use line-of-sight communication mode between transmitter and receiver. Using IR based system devices is convenient because the devices are compact, lightweight, and easy to carry out. The IR systems are precise with a good level of accuracy for indoor positioning. Besides these, IR based indoor positioning systems has some disadvantages mainly security and privacy issues and the requirement of additional devices since most mobile phones do not include IR.

Also, IR signals have some limitations for location determination in some circumstances, like interference from sunlight and fluorescent light. Another problem for this system is that it requires expensive system hardware and maintenance costs [21].

Another technology used is the Ultrasound system. The ultrasound system is a technology based on how bats navigate and it operates in the low-frequency band [27]. The ultrasound waves are used to estimate the position of the emitter tag from the receivers. Ultrasound can not penetrate through walls and reflects off most of the indoor surfaces and it suffers interference from other sources and the reflection of obstacles between tags and receivers [27]. However, it has a high level of accuracy [21].

Other IPS technologies are based on radio frequency, Radio waves have the advantage that can penetrate through indoor obstacles such as furniture, building walls and human bodies to some extent. Due to this, RF positioning systems have a larger coverage area and the need for less hardware compared to other IPS systems. RF based technologies can be divided into narrow band based technologies and wide band based technologies. The narrow end is used by Radio frequency identification (RFID), Bluetooth, wireless local-area network WLAN and frequency modulation FM, and the wide end are used by Ultrawideband (UWB) and RADAR [21].
Ultrawideband is a radio technology for short range using high-bandwidth communication. It has high accuracy from 20 to 30 cm. A typical UWB setup contains an emitter that generates radio waves and receivers which capture the propagated and scattered waves. The downside of UWB is that the hardware is expensive, making it costly for wide-scale use [21].
Radio frequency identification (RFID) is one way wireless communication using a non-contact and advanced automatic identification technology. It uses radio signals with specific ID from a tag, that can be placed on people or objects, then tracking the movements is done through a network of radio enabled scanning devices over a distance of several meters [21].
WLAN Based Indoor Localisation. Are the systems that use WIFI signals strength received in the device to obtain location. One of the advantages of using WiFi Positioning Systems is that almost every modern device is WiFi compatible, this requires less extra hardware and software for the system [21]. One major limitation of WiFi for positioning is the low scan rate. This is a combination of the inter beacon time and the dwell time in each channel, which typically results in a scan rate of 1 Hz on typical smartphones. Typical WiFi localisation accuracies are in the order of 3 to 5 m.

This makes it not precise enough for many applications [29]. Another problem is that it requires a complex set up and maintenance [21].

The ZigBee technology is a low power, low rate, low cost wireless technology standard. The technology is designed for short and medium range communication. ZigBee devices have a range of 10 to 75 meters based and the batteries can last months to several years [28]. Distance calculation between two ZigBee nodes is usually done by measuring the received signal intensity by applying inverse square law. ZigBee standard has problems due to interference from a wide range of signals using the same frequency which can disrupt radio communication between devices.

Bluetooth is a wireless standard for wireless personal area networks. Bluetooth has many advantages is of high security, low cost, low power, and small size, and as in the case of WIFI is present almost in any modern mobile device. It operates in the 2.4 GHz Industrial Scientific Medic (ISM) band. The main problem is that it uses too much power from the user's device for location purposes only. For that reason, the Bluetooth Low Energy (BLE) technology was created.

Hybrid positioning systems are defined as systems for determining the location of a mobile client combining several different positioning technologies by combining the advantages of different location technologies [29] this could be the combination of outdoors and indoors systems or different IPS.

This thesis focused mainly on the use of BLE as an IPS.

3. ABOUT BLE BEACONS

In this section, this study introduces the reader to the general concepts regarding the BLE beacons, different technologies that are used in Bluetooth low energy, approaches to indoor location as well as things to consider regarding the BLE beacons.

3.1. Bluetooth Low Energy

Bluetooth low energy is a technology that has been designed with two objectives in mind: to be the lowest possible power wireless technology and as a complementary technology to classic Bluetooth. Bluetooth technology uses radio waves operating in the unlicensed 2.4 GHz ISM band, which ranges from 2,400 to 2,483.5 MHz. The ISM band is open to any device and can operate worldwide [25]. The ISM specification is defined by the Federal Communication Commission (FCC). This part of the spectrum is widely populated with many devices broadcasting on these frequencies.

Bluetooth low energy signal has 40 different channels each separated by 2MHz. Three of them are dedicated to advertising and are located in between the most common WiFi channels. If the channels are set according to WiFi configuration best practices that prioritise the use of 1, 6, and 11 because these are the only channels with no overlapping. This WiFi set up should not cause interference on BLE beacons, as is shown in figure 2. To avoid further interference and fading it applies a frequency hop transceiver; this is done in order to get many devices to share this part of the spectrum without causing interference by jumping frequencies in short periods of time, no longer than 0.4 seconds [23, 25, 40].

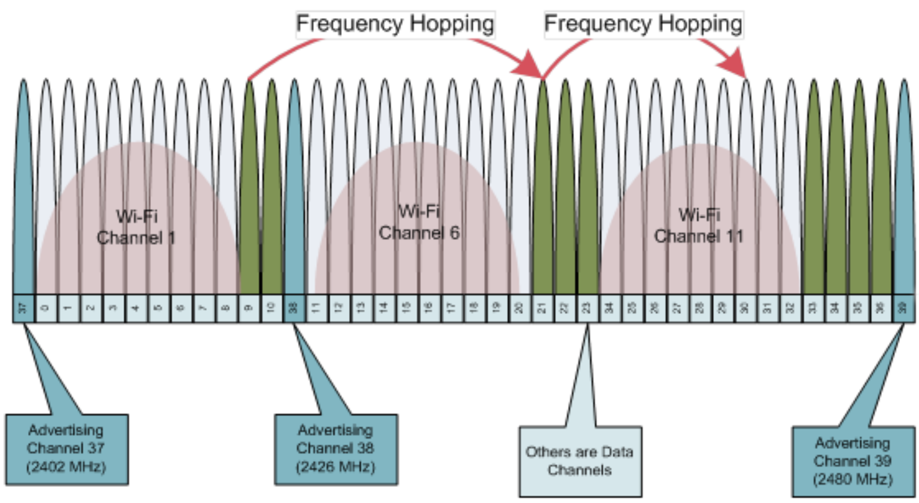

Figure 2. Representation of the distribution of bluetooth and WiFi channels.

In the case of some interference, the effects are not too big because the amount of data broadcasted by the BLE beacons is small. Although in some locations if the number of radio waves is big enough these effects could be noticeable [14, 25, 26, 39, 40].

3.2. Advertising

BLE beacons can only broadcast information, they can not connect with other devices. BLE beacons can not carry out any operations to calculate the distance to another device, all calculations must be done within the app in the device or in the server-side.

Bluetooth defines a single packet format for both advertising and data transmissions. This packet consists of four components: preamble, that is 1 octet, access address, 4 octets, Protocol Data Unit (PDU), 2-257 octets, and Cyclic Redundancy Check (CRC), of 3 octets.

The Protocol Data Unit is important as is the one carrying out the information. The PDU packet contains a 16 bit header and a variable size payload. There are several PDU types but typically beacons use ADV_NONCONN_IND, a protocol that specifies a non-connectable device. This makes the Bluetooth signal from the device to only advertise information to any listening device [26, 41].

3.3. Beacon Hardware

Beacons are mainly composed of a micro-controller with a Bluetooth LE radio chip, antenna, and power supply; this may be a battery, a USB or a power outlet.

There are several options for radio chip manufacturers, the two main ones are Nordic Semiconductors and Texas Instruments. There are several advantages to use some of these manufacturers or others depending on the requirements of the beacon. The same applies to the batteries; the overall size and the period of duration from a single set of batteries [1].

The antenna is also an important part of the hardware. Ideally, the radio signal from the BLE beacon propagates in a spherical shape where the wave strength is the same along a sphere but this is not the case; as seen in figure 3, different elements produce various wave shapes. [3,42]

Antennas can combine diverse elements to create changes in the shape of the propagating wave. Beacons are using specific antenna shape in order to produce radio

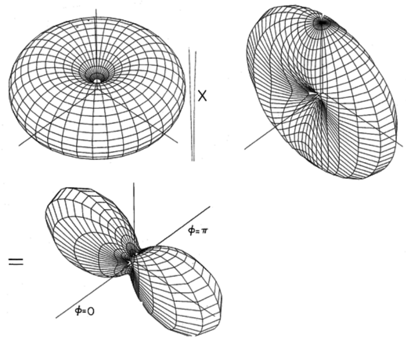

Figure 3. Antenna radiation fields for individual elements.

waves that propagate as uniformly as possible. But still, it does not create a perfect sphere. Therefore the signal strength is not always the same at similar distance points from the beacon.

3.4. Beacon Firmware

BLE Beacons have installed specific software to manage and operate the hardware. For beacons, there are two main variables that affect the performance and battery life.

Transmit power (TX power):
Beacons broadcast their signal with a fix base power, known as the TX power. This is the factor that indicates the range of a beacon, as the signal travels through space the signal strength that other devices receive from the beacon decreases by the inverse square law, see Figure 4,

The more TX power a beacon has the more range it can get but this also affects the energy consumption of the beacon. Depending on the beacon and the use of it more or less power is required. In the 2.4GHz ISM band, there are limits to the maximum

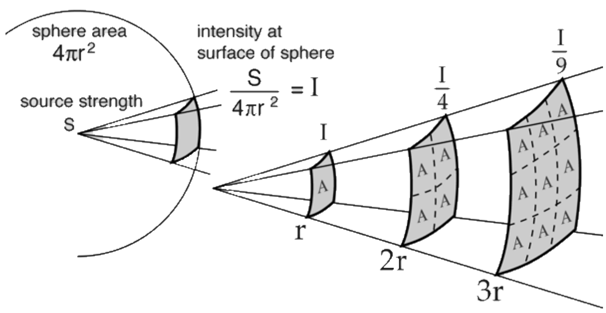

Figure 4. Inverse square law formula and representation.

transmit power that a device can use to stay within the license-free regulations. For Bluetooth low energy, the specification limits the maximum transmit power to +10dBm. The BLE specification also imposes that there is a minimum transmit power of -20dBm, so devices cannot be made so quiet that no other devices can hear them.

Advertising Interval:
The advertising interval is another parameter that affects the accuracy and the battery life of the beacon. [5] The interval setting determines how often a beacon broadcast its advertising packet. Commonly measured in milliseconds (ms), it can also be measured in seconds at the highest interval ranges. At the moment there are not many applications where using long intervals is found particularly useful. This may change in the future. Studies show that higher interval settings (over 700 ms) cause problems with signal stability. Apple's iBeacon best practice recommends 100 ms whereas some beacon manufacturers found that a slightly longer interval (350 ms) produces the same stability and more battery life. Of course, these settings are related to the uses of the beacon. There are situations where battery life is not a priority or the beacons are connected to a socket and do not depend on batteries. And there are situations where higher accuracy is needed. In these cases, a lower interval (20 ms) may be required. In the case of a person walking through a network of beacons, study shows that there is not that much different from the lowest interval to the 100 ms or 350 ms [4].

3.5. Battery Effects

The device using BLE beacons for location may suffer a higher battery consumption but this increase does not seem to be critical. Some reports indicate about 1-3% over the course of a day. [4]

In the other side BLE beacons battery life depends on the device; what batteries it uses and what is the power output of the signal. The output signal can be modified by the user. The battery power beacons on average last from months to a few years. For this matter depending on the set up the beacon network maintenance is really small as the changing of the batteries is simple [4].

3.6. Location Technics

There are different approaches to the use of BLE beacons for indoor location purposes. This study leaves out triangulation algorithms, because there is not accurate synchronise clocks within the beacons to use in a beacon network. It is not possible to compare these accurate readings of time and distance.

Beacon proximity:

Beacon proximity is the way to get the location by measuring the RSSI of one beacon a certain intensity that is known to be of a specific distance, used for calibration. In this way when the intensity of the signal is measured it can be deduced the distance from the device to the beacon. By applying the inverse square law between the known calibration measurement and the current one. iBeacon does that automatically and groups the results in three proximity ranges; the closest is called immediate and is between 0 and 0.5m. The next one is called near and it ranges between 2m to 5m approximately. The last one is called far and it is from 5m and higher. The accuracy is not reliable for these measurements therefore these distances should be taken as an approximation [1,5,12, 44].

Trilateration:

Trilateration is the way of getting the location based on the readings of the RSSI of at least 3 beacons and combined these to get an approximate location. This idea is illustrated by figure 5.

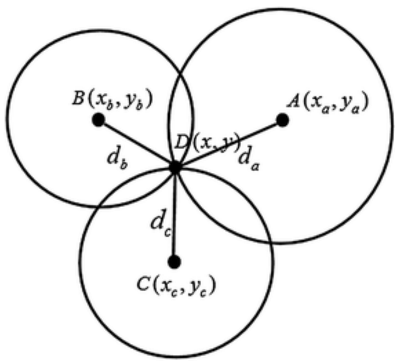

Figure 5. Diagram of basic trilateration.

Trilateration is in the base of indoor navigation. When it is used alone is not the most accurate solution but with added beacons and the combination of other technics can largely improve the accuracy.

Particle filter:

Particle filter or sequential Monte Carlo (SMC). This technic uses measured samples and a set of Monte Carlo algorithms to process the signals. This technic is used in combination with trilateration to get more accurate results. One study claims that in a small space they got errors as low as 0.27m and 0.97m [22] on a larger space by a combination of particle filter and increasing the number of beacons. The study also found that there is an equilibrium for the number of beacons and the accuracy; when the number of beacons is increased to some extent the accuracy decreases significantly due to the effects of interference. The study does not give an exact number of beacons for any space as the number is related to the distribution and topography of the location where the beacon network is set. Therefore this technic requires planning before deployment and some testing to obtain the best results possible [22].

Fingerprinting:

Finger printing is another technic used to improve the results on accuracy when using trilateration. The idea of fingerprinting is to create a database with the measurements of signals received from different known positions on the specific location. The goal is to create a map that links measured signals with specific locations [14]. The database can be used by an application to contrast the readings and assign a location based on the closest known point and the particular reading. This approach improves the accuracy of the system. But there are some drawbacks to take into consideration. It requires a more complicated set up because of the need for a database for a specific location. If new beacons are introduced the entire database needs to be updated. And in the case of interference, or if one beacon runs out of battery or turns off, the outcome of the system can be compromised. In this case, the fingerprinting accuracy is decreased to the extent that renders not an improvement at all.

Core Location:

Apple's core location services integrate with Apple's iBeacon. Core location uses a combination of GPS, cell tower and WiFi networks to get a more accurate position inside buildings. This alone is an improvement as to use GPS alone, adding some increase in system accuracy. The combination of this improvement with a beacons network increases the accuracy of a smaller granularity [43].

Depending on the needs of the project some of the approaches may work better than others. This study looks at particular technics in the scope of the restaurant business and how are the different approaches producing better results for these environments.

Another consideration is that if the calculations are done on the device, these are limited by the device power and speed. For better performance and more complex algorithms, the application can do the computation on the server-side, as they have less limitation of resources and are much more powerful machines than mobile devices, though there is a rise in the complexity of the application.

3.7. Frameworks for the Beacon Broadcast Signal

There are several frameworks for BLE beacons broadcast signals. The most important ones are iBeacon from Apple, Eddystone from Google and Altbeacon; an open-source framework developed by Radius Network.

iBeacon:
iBeacon was introduced by Apple in mid 2013. This was the first BLE beacon technology to come out and is the most popular beacon framework. It works with IOS and Android platforms. Though it works with better performance on Apple devices as the application does not require to be running, it uses operating-system management and it can wake up an application even if it is close. For Android, the Bluetooth scan must be done by the application. For that reason, it must be running in the foreground or the background to work with iBeacons[1,5,6,20,26,44].

The broadcast signal, as illustrated in figure 6, for iBeacon consist of 31 Bytes of data divided into five parts, four of them carry out the specific iBeacon information.

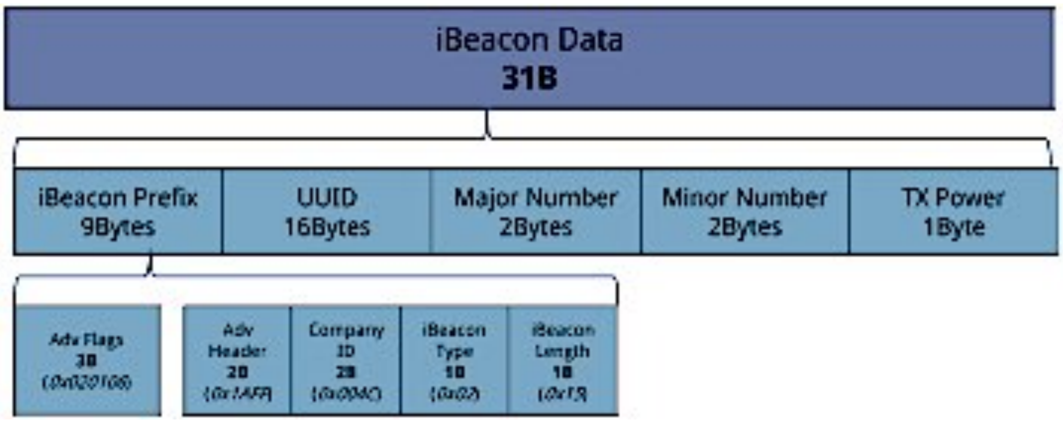

Figure 6. iBeacon advertising packet.

- The first part of the signal is the iBeacon prefix. This part contains the hexadecimal data: 0x0201061AFF004C0215. The data of the prefix encodes the following information:

0x020106 defines the packet as a BLE General Discoverable and BR/EDR high-speed incompatible. This specifies that the beacon is only broadcasting, not trying to connect.

0x1AFF indicates the size of the following data, 26 Bytes long and is specific data from the manufacturer.

0x004C This is Apple's Bluetooth sig ID, the company identifier related to the protocol.

0x02 Is a secondary ID that denotes proximity beacon and is used by all iBeacons.

0x15 Is for defining the remaining length of the message, that is 21 Bytes (16+2+2+1)

- The rest of the packet is the part that is used to carry information about the specific iBeacon:

- UUID This is 16 Bytes long and is the only mandatory information. It is used to identify the beacon.

- Major number: This number is used to group the beacons of a network.

- Minor number: This one is used to find a specific group or beacon inside the Major group.

- TX power: This is the calibration number and indicates the signal strength measured at 1m of distance from the beacon. This should be carried out by the user or manufacturer for each iBeacon. Proper calibration is important to have better accuracy.

iBeacon integrates well with IOS devices and works cross-platform, also is easy to implement and integrate with Apple’s Core Location [5,20,26,44].

EddyStone:

Eddystone was released by Google in mid 2015. It was named after the famous lighthouse in the UK. The main difference with iBeacon is that it is open-source, that the frames are flexible and that it supports other uses for the beacons, as in advertising information. Thought implementation is a bit more complicated than Apple's iBeacon. Eddystone uses two advertising packets, Eddystone service UUID and Eddystone URL. A diagram of the Eddystone broadcast packet is illustrated in figure 7. The image

shows how these packets fit in the broadcast signal of Eddystone.
Eddystone was developed with the intention to be used for the Physical Web more than to location technics.

- Eddystone service UUID can broadcast the information in a public manner, Eddystone-UID, or encrypted, Eddystone-EID:

  Eddystone-UID is a universal ID that is unique for each beacon. The length of this frame is fixed and is 31 bytes. It starts with the frame type followed by the TX Power, which for Eddystone is calibrated at 0m. And then the UUID of 16 bytes size, that is composed of a 10 byte namespace and a 6 byte instance.

  Eddystone-EID broadcast is an encrypted ephemeral identifier that changes over time at a determinate rate that is set during the initial registration with a web service. This frame is intended for security and privacy. The EID frame is encoded in the advertisement as a Service Data block associated with the Eddystone service UUID and is 8 bytes long.

- Eddystone URL is a frame used to broadcast a URL using a compressed encoding format. The compression is used to fit more information into the limited advertising packet. The Eddystone URL frame is the core of the Physical Web that is Google's effort to enable an easy way to discover web content related to the user surroundings. The packet is divided into four parts. The first one is the frame type which has a Hex value of 0x10. The next one is the Tx power, measured at 0 m. For Tx power calibration can be done either at 0m or at 1m with an adjustment of plus 41dBm to the value (this is the signal loss that occurs over 1m). The next one is the URL Scheme Prefix this is an encode for the beginning of the URL address. The last part is the Encoded URL that has a length from 1 to 17 bytes.

- Eddystone TLM is used to get telemetry, transmits information about the beacon operation. It is useful to monitor the health and operation of the beacons. This frame does not contain an ID therefore it requires to be paired with Eddystone UUID or Eddystone URL to provide the ID. TLM frames can be broadcasted unencrypted like UID and URL frames or if the beacon has been configured encrypted with Eddystone EID

- Unencrypted TLM frame is divided into six parts: the first is the frame type, which is 0x20 for the TLM. Then the TLM version. Followed by the battery charge measured in millivolts. After this comes the beacon temperature, measured in Celsius. Then comes the advertisement count since power-up or reboot. And finally comes the

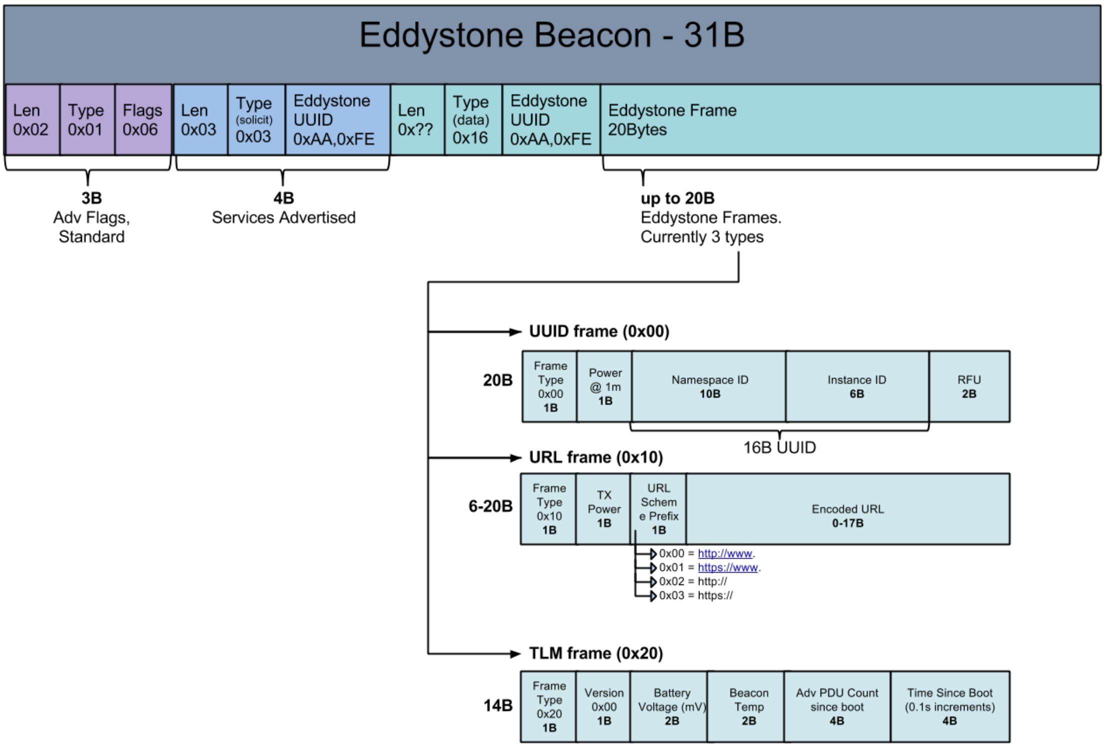

Figure 7. Eddystone advertising packet with the non encrypted options.

time that beacon has been operating since power on or the last reboot.
Encrypted TLM The first two parts of the frame are similar to the unencrypted one but the version has a different number. After this it comes 12 bytes of Encrypted TLM data. Then 16-bit random salt and after this the 16-bit integrity check tag.

AltBeacon:

Around 2015 Radius Network launched a new standard for beacon. AltBeacon is an open and interoperable proximity beacon specification. The main feature of this framework for beacons is that it is open-source. AltBeacon uses a partially similar broadcast packet as the iBeacon so it can be easily integrated with it. The broadcast packages are divided, as seen in figure 8. The AltBeacon part is a 28 Byte long, of which 26 Bytes can be modified by the user.

The first two bytes of the AltBeacon are set by the BLE stack, and can not be modified.

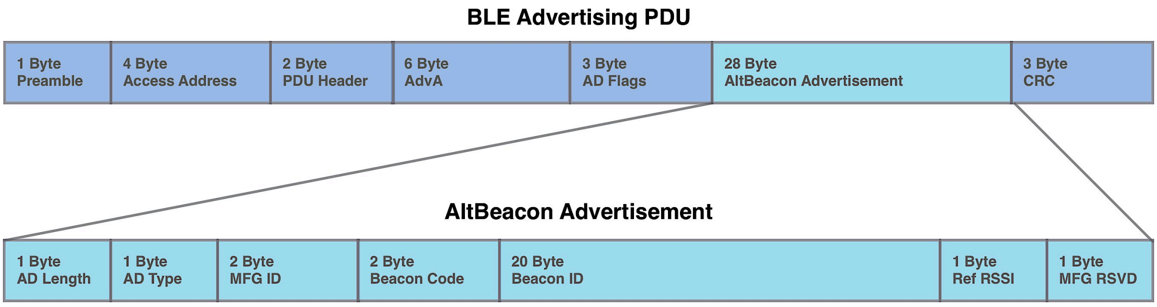

Figure 8. The AltBeacon broadcast packet inside the BLE beacon broadcast Protocol Data Unit.

ADV Length is 0x1B and ADV Type is 0xFF; these will specify the length of the advertising data packet and the type as manufacturing data respectively. The rest of the packet can be changed by the user. By default, it uses a UUID, a secondary ID (similar to the major), a third ID (similar to the minor), and a RSSI for calibration measured at 1m. AltBeacon includes after this an extra field of data of one byte that can be used for different purposes, for example to indicate battery level or temperature, but ultimately is the manufacturer's choice to implement the features in this field [6].

3.8. Indoor Map

For the creation of the map to be used as a reference for the user. It depends largely on the needs of the project. Due to the scope of this study, this thesis does not look too much into how to develop highly specific maps. It is found to be sufficient for representation a simplified 2D map of the space. In the case of using Apple's Core Location, it needs two anchor points within the map created linked to exact chordates to combine the indoor map with Apple maps.

3.9. Moving Devices

Another factor to take into account is the movement of the device that is receiving the signal as this fluctuates drastically to get an accurate location or path. These effects are only noticeable in the cases of devices moving faster than the average speed of a person walking. For this study, is not a major concern, as the most probable scenario is that the customer is sitting at a table when the location needs to be measured. But an increase in the interval time would get better results in these circumstances.

4. USING BLE IBEACON PROXIMITY FOR LOCATION

In this section, the study focused on using BLE Beacon Proximity setups to obtain the desired results. This was achieved by testing in control environments and analysing the results. This chapter also describes the tools used to achieve those results. Beacon Proximity, as mention in the previous section, is based on the readings of one known Beacon to calculate the distance from the device to the beacon and if the device is close enough to assign the location of that particular beacon.

4.1. First Test: iBeacon Proximity for Location (One Table)

This test was designed to find the viability of using a single beacon placed in a table to obtain a reliable location of a user on an indoor location. This test was made as a proof of concept, for this reason, it was used the most simple set up possible. This method is convenient to use because the set up is straight forward and easy to implement.

In order to continue with a large beacon deployment, it was decided to first test it with only one beacon and one device to read the position. The test was carried out at Tenho restaurant in Helsinki. In this particular restaurant, all tables were made out of wood and there was mainly three different sized tables: one big one that fits around eight people; one medium size that fits from four to six persons and finally one small one that fits around two to three costumers.

4.1.1. First Test Set Up

This test was carried out with an iPhone X transmitting an iBeacon signal [11] as the beacon and one iPhone 5s as a receiver device. For this initial test, an application from the Apple store was used to get the proximity values. It was decided to use a third party application first for the initial test and create a testing application later. The application used was the Locate app to transmit the iBeacon signal as well as for the readings and calibration.

Calibration was an important part of the process, This study noticed that in different environments the values obtain for calibration have a discrepancy between them, even though these would be small differences there is a chance of getting different results. For this reason, the beacons were calibrated in the same room where they were tested. The app Locate was used for calibration as it was the one used and had a calibration feature.

For this test, the beacon was placed with tape under the table and located in the middle of the table. The Tables were separate for a distance of about 1m. The readings were made by sitting at all the chairs on each table and all the chairs of all the nearest tables as well as standing in different places near the table. When sitting at the table the device was placed on hands and over the table.

- Test 1.1 The beacon was placed under a wooden table. The table size was 1.80m x 1.0m.
  The readings were consistent of *near* over all points off the table sometimes *immediate* when the device was placed close to the middle of the table and *far* at other tables of distances from 1m to 2m.

- Test 1.2 beacon placed under a wooden table with metal legs. The table size was 1.20m x 0.60m.
  The readings were between *immediate* and *near* overall positions at the table readings of *far* at other tables in several places that were on average at distances of 1m to 2m.

- Test 1.3 beacon placed under a wooden table with one metal leg. The table size was of 0.60m x 0.60m.
  The readings were between *immediate* and *near* at all points on the table and of *far* at other tables from distances of 1m and more.

4.1.2. First Test Results

The average results have been displayed on a floor plan, see figure 9, to help with the visualisation of the results. This map represents the proximity values colour coded. The

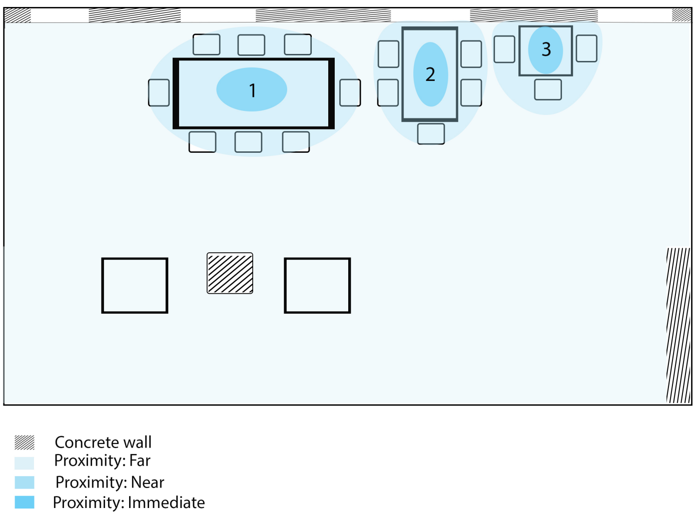

Figure 9. A floor plan showing the average beacon proximity readings.

areas have been average from the readings. The *near* readings were the most common ones at the position on the chosen table. *Immediate* readings were more common on the smallest tables and when the device was placed laying on the table surface. *Far* readings were always outside the table and at other tables.

From this test was deduced that it's possible to obtain accurate enough location from a single beacon to locate a customer in a table inside a restaurant. As the results were consistent in that the device readings outside the chosen table were *far* and *immediate* and *near* when sitting at the table. But this test was not conclusive enough on how a beacon network behaves in more complex situations. But this gave a good starting point for more real life-like test.

4.2. Second Test: iBeacon Proximity for Location (Multiple Tables)

After the first test, this study showed the viability of using beacon placement at tables for the purpose of location inside a restaurant. In this second test, the goal was to emulate a more realistic situation. For this test, a simple application was developed that tells what table the user is located. And the table set up was a bit different, four beacons were placed in a group of four medium-sized tables that were close to each other.

4.2.1. iOS Application

The scope of this study is intended for the use of iBeacon with iOS devices. For that reason, this indoor location approach was tested with an iOS application. The application was created using swift 4 and Apple's SDK. The development happened inside Xcode. It only required the import of the Core Location dependencies.

For this test a single view application was sufficient. The application displays a text that indicates what table the user is if any it is found to be in *near* or *immediate*. In the case of all the beacons being *far* or *unknown,* it displays “not table found”.

The application listens to the iBeacons of a specific region. This is specified by UUID, in this case. It can also be specified by the UUID, Major and or Minor numbers. This prevents the application of listening to unwanted beacons.

The application creates an array of objects. This array of objects is populated by the values of the iBeacons from a certain region, which signals are in range. By default this array is sorted by proximity, starting with the closest beacon, this refers to the closest by the measured signal. With the exception of beacons that have a proximity value of *unknown.* In this case, the return value is 0 and the beacon is placed at the beginning of the array. To avoid the usage of these beacons by the application, a filter was added to remove any unknown beacons from the array. Finally, if the returned array is not empty the application takes the first index from the array, the beacon with the closest proximity value. In case of equal proximity values between beacons, the beacon with the highest RSSI value (this should be the closest one) is placed first. Then the application evaluates if the proximity value is *immediate* or *near.* In the case of being true, then it returns the Minor value. The table number is encoded in the Minor value. The application prints the table number on the screen. If no beacon is found matching the criteria it returns “not table found”. Below, in listing 1, is a part of the code that was implemented:

```
func locationManager(_ manager: CLLocationManager, didRangeBeacons beacons:
[CLBeacon], in region: CLBeaconRegion) {
    print(beacons)// Prints beacons in to the console
    // Remove the unknown beacons
    let knownBeacons = beacons.filter{$0.proximity != CLProximity.unknown }
    if (knownBeacons.count > 0){
      let nearestBeacon = knownBeacons.first!
      let table = CLBeaconMinorValue(truncating: nearestBeacon.minor)
      let whichTable:String = {
        switch nearestBeacon.proximity {
            case .near, .immediate:
              self.view.backgroundColor = UIColor.green
              return "You are in table \(table)"
            case .far:
              self.view.backgroundColor = UIColor.red
              return "please sit at a table”
                }}()
      displayLabel.text = whichTable
    }
```

Listing 1. Obtaining the table value from the closest beacon in the *near, immediate* range in swift 4.

The function in the code shown in listing 1 takes the return array from the beacons in range and then returns the table number if the device is close enough. For debugging purposes, it prints the beacons array into the console. The log output looks as follows:

[CLBeacon (uuid:E2C56DB5-DFFB-48D2-B060-D0F5A71096E0, major:1, minor:5, proximity:2 +/- 2.78m, rssi:-67), CLBeacon (uuid:E2C56DB5-DFFB-48D2-B060-D0F5A71096E0, major:1, minor:3, proximity:2 +/- 5.27m, rssi:-72), CLBeacon (uuid:E2C56DB5-DFFB-48D2-B060-D0F5A71096E0, major:0, minor:4, proximity:3 +/- 5.99m, rssi:-73), CLBeacon (uuid:E2C56DB5-DFFB-48D2-B060-D0F5A71096E0, major:1, minor:2, proximity:3 +/- 18.96m, rssi:-81)]

Listing 2. Log output of the *beacons* array from the function on listing 1.

As shown in listing 2 the return beacons is an array of CLBeacon objects. CLBeacon object is composed of the values of UUID, Major, Minor, Proximity, distance, and RSSI. The distance value is deduced from the RSSI, the calibrated value and the inverse square law, this value is not always accurate. Proximity values are 1 for *Immediate,* 2 for *near,* 3 for *far* and 0 for *unknown.* In this case, all the beacons used for this test had the same UUID and same Major value. For each beacon a different Minor value was assigned for each beacon, that represented the table number. In this particular log the table returned would be number 5 because it is the first on the array and it has a Proximity value of 2 (near).

4.2.2. Used BLE Beacons

This part of the study looks at the iBeacons configuration and the beacons models used for this particular test. Kassamagneetti Oy provided a set of BLE beacons. These beacons were Satech STiE4 as shown in figure 10. This BLE beacon uses a Nordic

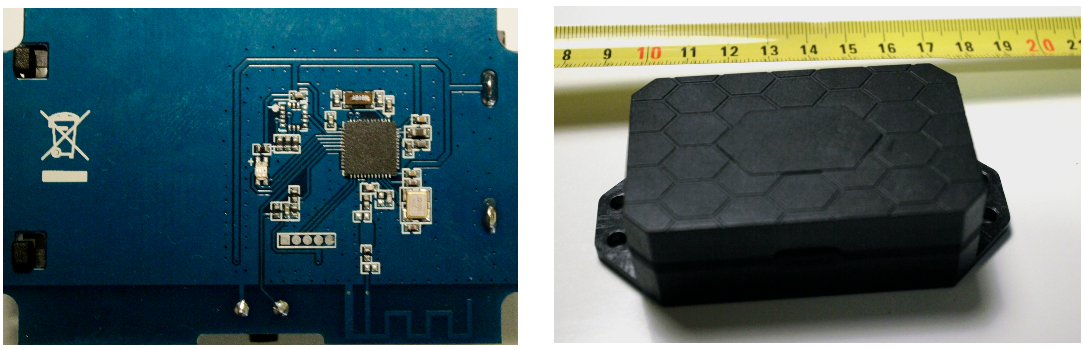

Figure 10. Satech STiE4 beacon chipset and enclosure.

Semiconductor nRF52832 with 64 MHz ARM Cortex-M4F chipset that is Bluetooth 5 capable and comes with 512 KB Flash memory and 64 KB RAM.

The Advertising Interval can be set between 100 ms and 5000 ms, and the Transmitting Power can be adjusted from 4 dBm to -30 dBm. These BLE beacons are powered by two AA batteries and can last from 2 to 5 years depending on the settings [45].

Most of the manufacturers are supporting beacons with an application made to access the firmware and be able to configure the BLE beacon settings. But this was not the case of Satech LTD. They refer to a German company called KingApp which after weeks of slow communication did not provide any helpful results, nor an application nor information about the beacon API. This lack of support caused delays in the testing carried out by this study. For that reason, these beacons were not used in this test. It was not possible to use the Satech BLE beacons with the factory settings, they were not reliable. Without any means to configure they could not be used.

An alternative set of BLE beacons were used for this test. A small set of April Beacon EEK were used. The beacons come with a Dialog DA14580, 16 MHz, 32 bit, ARM, Cortex-M0 chipset. They have Bluetooth 4.2 specification. In terms of memory these beacons come with 1 Mb flash memory, 32 KB of OPT memory, 42 KB System SRAM and 84 KB of ROM. The beacon chipset and casing can be seen in figure 11. This chip is more focused on lower power consumption. April beacon introduced a different chip in the new model EEK-N, It uses a Nordic Semiconductor NRF52810 64 MHz 32-bit

ARM Cortex-M4 chipset with Bluetooth 5. It has 192 KB Flash Memory and 24 KB of RAM.

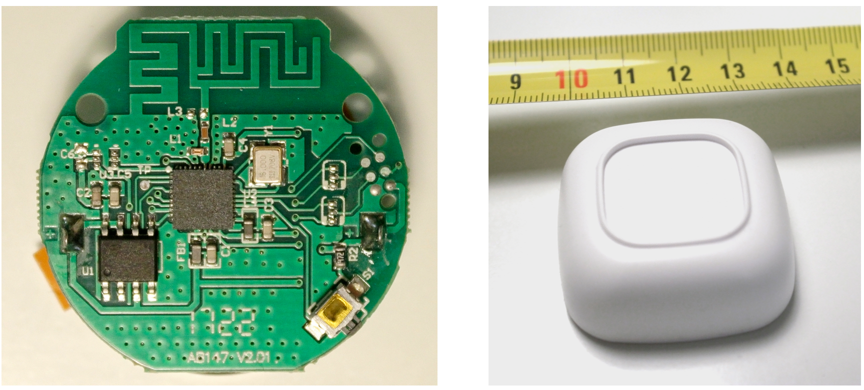

Figure 11. April Beacon EEK chipset and enclosure.

The chipset is smaller in this model. The antenna has a more complex design to allow the signal to reach further on the same power output. The Advertising Interval can be set around 100 ms intervals between 100 and 1285 ms. For the TX power it has 2 options: 0dBm or -20dBm. It uses a CR2450 battery of 1000 mAh. The company claims that it can last from 1.5 to 5 years depending on the settings. This model has simpler maintenance as it does not require to be detach from the placement when changing the battery [46].

4.2.3. Second Test Set Up

This test evaluated the reliability of obtaining table location at a restaurant with multiple beacons that were set up in a group of tables. The tables were of medium-sized and were grouped close together with distances of under a meter on the closest points, this is closer than what is most commonly found in restaurants. Similar to the previous test the BLE beacons where placed under the tables. All tables where made of a wooden top and metal legs. The beacons were set up with a TX power value of 0 dBm and Advertising interval of 100 ms and of 200 ms. The calibration for the beacons was carried out in the same room. The testing application was running on iPhone 5s.

4.2.4. Second Test Results

The results of the second test were successful. At all the position of the tables the readings from the application were correct. As shown in figure 12 The results were also

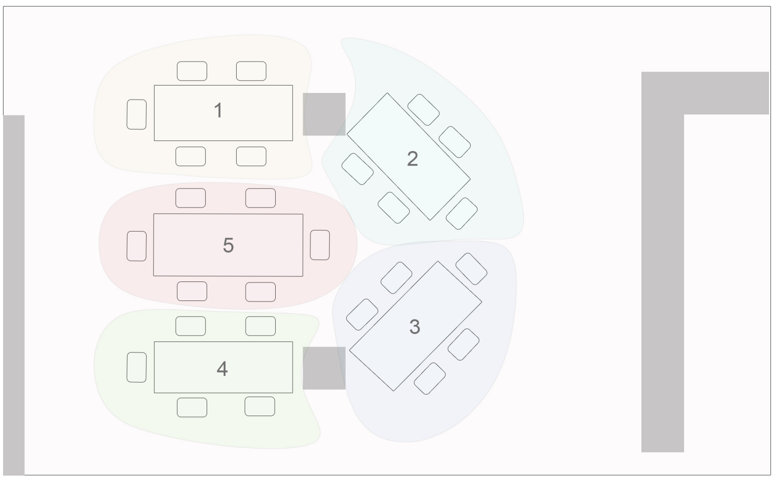

Figure 12. Representation of the average position readings from the application on table location.

positive when there were more people at the tables probably because their body only interfered with the signals from other beacons and not with the one at the table. Also, there were no negative results when people were standing by around at the location.

The readings from the application were satisfactory even at the positions on the table that was closest to other tables. The way the algorithm works helps in these situations because it always takes the Minor value from the first beacon from the array, which is the closest one to the device. For this reason, the application assigns the location of the closest beacon to the device even though other devices may be in *near* range.

4.3. Third Test: iBeacon Proximity for Location (Table Size Limit)

This test was designed to find the limits of using an iBeacon Proximity values from single iBeacon on a single table. The idea was to find the limits of this approach. In the previous test the result showed that this technic worked well in the tables that were tested. Because of how the iBeacon Proximity works this study suggested that there would be cases with bigger table sizes in which the results could be negative. The goal of this test was to find the upper limit of table size that can be implemented using the iBeacon Proximity method for location.

4.3.1. Third Test Set Up

The set up for this test was done by placing two tables close to each other. One of the tables was medium-sized and the other one was of bigger size, this one was increased in size every step of the test until the critical size was found.

The starting point for the bigger size was similar to the bigger table used on the first test of 1.80m length with the beacon set in the middle and under the table. Then the size was incremented by 0.60m and the beacon repositioned to the center of the table. A difference from the previous test is that this big table is not made of one piece but composed of smaller tables join together. The tables were of 0.60m by 0.60m with a wooden table top and a metal leg.

The beacons used were the same as in the second test; the April Beacon EEK at 0 dBm TX Power and 100 ms Advertising Interval.

4.3.2. Third Test Results

The third test results showed that when the table was bigger that 1.80m the results were not positive at the outermost parts of the table. In the table of 2.40m by 0.60m that was tested the application readings were negative. As shown in figure 13, at points were readings were taking on both ends of the table showed not table and some of these points were reading nearby tables.

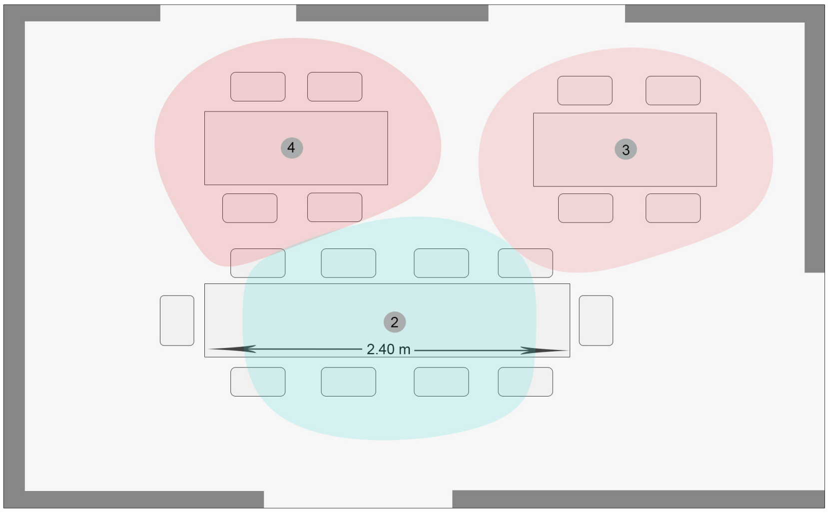

Figure 13. Visual representation of the average readings from the application on table location.

These test results showed a limit of table size of one beacon per table system. Tables bigger than 1.80m by 1.00m are not reliable enough to get an accurate reading from one beacon alone.

Also in this test was noticed a decrease on radio signal intensity from the beacon across the table in comparison with the previous test. This was mostly caused because the tabletop on the tables used on this test was slightly thicker than the previously used. This shows that the thickness of the material could affect the results slightly.

In the restaurant where the test was carried out all the tables did have a wooden top. Other materials (marble, metal, plastic, among others) may also affect the results. Although it is reasonable to assume that these changes would be noticeable only in bigger size tables. Of course, this problem can be overcome by placing more beacons per table and assign to all of these ones the same Minor number.

5. USING BLE BEACON TRILATERATION FOR LOCATION

This part of the study tested and analysed the use of trilateration with BLE Beacons to obtain an accurate location. The test goal was to find out if the trilateration approach could be use to assign a table for a customer. It was decided to start with a simple approach to trilateration and to analyse the results to better understand what future requirements were needed.

5.1. Fourth Test: iBeacon Trilateration for Location

This test was designed to find the accuracy and reliability of using trilateration for table location inside an indoor location. The test was carried out inside a smaller room of a restaurant in Helsinki. Five BLE beacons were used that were placed in different positions around the room. One receiver took readings from six different locations inside this room. In the iBeacon signal, there are several values, as previously shown in listing 2, some to indicate which beacons the signal is coming from and others to tell the distance from the beacon. For trilateration the RSSI value and the distance to the beacon. This distance is derived automatically by Apple SDK.

5.1.1. Fourth Test Set Up.

The test was carried out in a smaller room of the restaurant. This way it required an easier and more control set up than in the main hall of the restaurant. The size of the room was about 6m by 4m, the hight was 3.20m from the floor to the ceiling. Two of the walls were made of concrete and the other two of drywall. The space had two windows. The set up of the room, as shown in figure 14, had six small tables, of 0.60m by 0.60m, placed slightly separated from each other. For this test 5 beacons were placed at different locations in the room to get the clearest coverage possible. Two of the beacons were placed on the ceiling and the other three on the walls. The ones placed on the walls were placed at about 2.20m from the floor.

The BLE beacons that were used were similar ones to the previous test. iBeacon signal from the April Beacon EEK at 0 dBm TX Power and 100 ms Advertising Interval.

The device used for reading was an iPhone 5s running the testing application and the data was retrieved from the application logs; This contained the returned object beacon

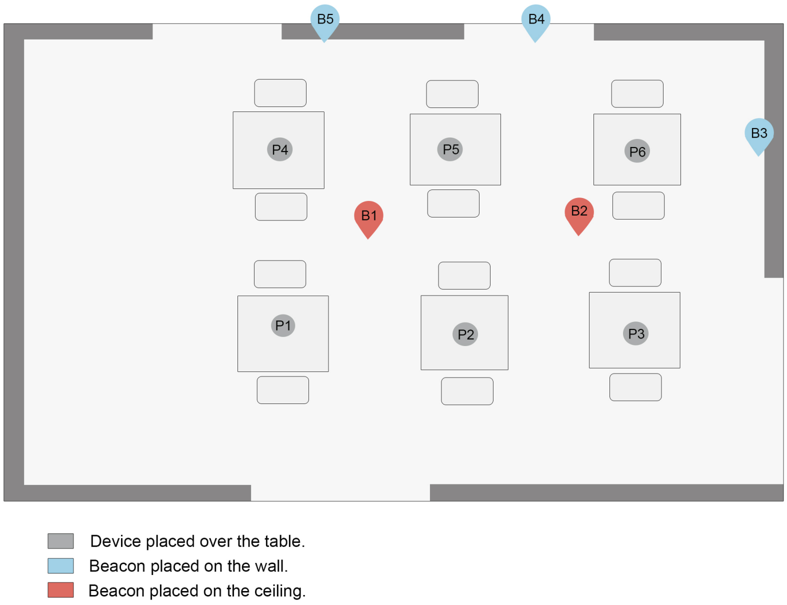

Figure 14. Space set up for the fourth test, Beacon placement and reading positions.

array, similar to listing 2. The readings were made at one position per each table. While holding the device with one hand.

5.1.1.1. Test External Factors

In this part are listed other things to take into consideration from the test and how it was setup.

To compare the readings that were given by the application derived from the signal intensity on the device. The actual distances from each beacon to the point of readings were measured. The measurements that were taken were not exact but with an accuracy of ± 0.05m.

The readings from the device were taken for a small period of time that returned the beacon array around twenty times. This was to obtain several samples from the same location to compare the signal stability.

While the test was been carrying out there was only one person in the room. These results do not reflect the possible signal attenuation that could be caused by a larger number of people in the room.

5.1.2. Fourth Test Results

This test had more level of complexity than the previous tests carried out by this study. There are different aspects that can be deduced from this test.

5.1.2.1. Signal Stability

The first point analysed is the stability of the measured signal. The goal was to find out how under similar circumstances the signal reading values changes.

A shorted values of the recorded logs from the test can be seen in table 1. It displays values from each beacon at each of the measured positions. To make the data more

Beacon / Position	iBeacon 1 min	iBeacon 1 max	iBeacon 1 ave	iBeacon 2 min	iBeacon 2 max	iBeacon 2 ave	iBeacon 3 min	iBeacon 3 max	iBeacon 3 ave	iBeacon 4 min	iBeacon 4 max	iBeacon 4 ave	iBeacon 5 min	iBeacon 5 max	iBeacon 5 ave
Position 1	0.84 m / -58 rssi	1.47 m / -62 rssi	1.27 m / -60 rssi	1.66 m / -67 rssi	2.42 m / -75 rssi	2.18 m / -72.7rss	2.41 m / -61 rssi	5.42 m / -75 rssi	4.28 m / -69 rssi	1.96 m / -62 rssi	3.07 m / -68 rssi	2.7 m / -66 rssi	0.77 m / -57 rssi	1.15 m / -61 rssi	0.87 m / -58.5rss
Position 2	0.78 m / -56 rssi	1.10 m / -59 rssi	0.89 m / -57 rssi	0.94 m / -66 rssi	1.36 m / -71 rssi	1.19 m / -68.4rss	Unknown	Unknown	Unknown	2.82 m / -66 rssi	5.99 m / -73 rssi	3.33 m / -68 rssi	3.16 m / -68 rssi	4.49 m / -72 rssi	3.9 m / -70 rssi
Position 3	2.02 m / -63 rssi	3.16 m / -67 rssi	2.3 m / -64 rssi	1.24 m / -67 rssi	2.01 m / -73 rssi	1.5 m / -70 rssi	0.77 m / -57 rssi	1.24 m / -62 rssi	1m / -59.4 rssi	3.07 m / -67 rssi	3.59 m / -69 rssi	3.35 m / -68 rssi	2.8 m / -66 rssi	6.9 m / -76 rssi	4.85 m / -73 rssi
Position 4	0.76 m / -55 rssi	1.52 m / -62 rssi	1.03 m / -58.5rss	1.8 m / -71 rssi	6.81 m / -82 rssi	2.52 m / -74 rssi	1.31 m / -61 rssi	2.41 m / -71 rssi	1.79 m / -64 rssi	1.14 m / -60 rssi	1.73 m / -64 rssi	1.38 m / -62 rssi	0.41 m / -52 rssi	0.57 m / -55 rssi	0.47 m / -53 rssi
Position 5	1.15 m / -59 rssi	1.99 m / -65 rssi	1.46 m / -61 rssi	0.68 m / -64 rssi	1.23 m / -70 rssi	0.97 m / -67 rssi	1.04 m / -59 rssi	1.67 m / -64 rssi	1.23 m / -61 rssi	0.41 m / -51 rssi	0.53 m / -54 rssi	0.47 m / -53 rssi	1.0 m / -59 rssi	2.03 m / -68 rssi	1.6 m / -63 rssi
Position 6	1.69 m / -62 rssi	2.19 m / -65 rssi	1.90 m / -63 rssi	0.56 m / -62 rssi	0.82 m / -67 rssi	0.71 m / -64.5rss	0.73 m / -56 rssi	1.13 m / -61 rssi	0.91 m / -58 rssi	0.73 m / -56 rssi	1.06 m / -61 rssi	0.85 m / -58 rssi	1.95 m / -64 rssi	2.59 m / -68 rssi	2.25 m / -65 rssi

Table 1. The maximum, minimum and average values obtain from the iBeacon readings from the device.

readable only the maximum and minimum values as well as the average are displayed.

The signal intensity fluctuates even though the device was not moving. The reasons for these changes in values are related to many factors and non-constant for the same beacon. Never the less this is an issue that reduces the reliability from a single measurement of a beacon for obtaining an accurate location.

To visualise the signal fluctuation, see figure 15, that illustrates the difference between maximum and minimum values of RSSI from each beacon per location. This translates to the distance in different ways depending on how close to the beacon the device it is but if we look at this test results at maximum the discrepancy is of 3.01m from readings from the same point to the same beacon.

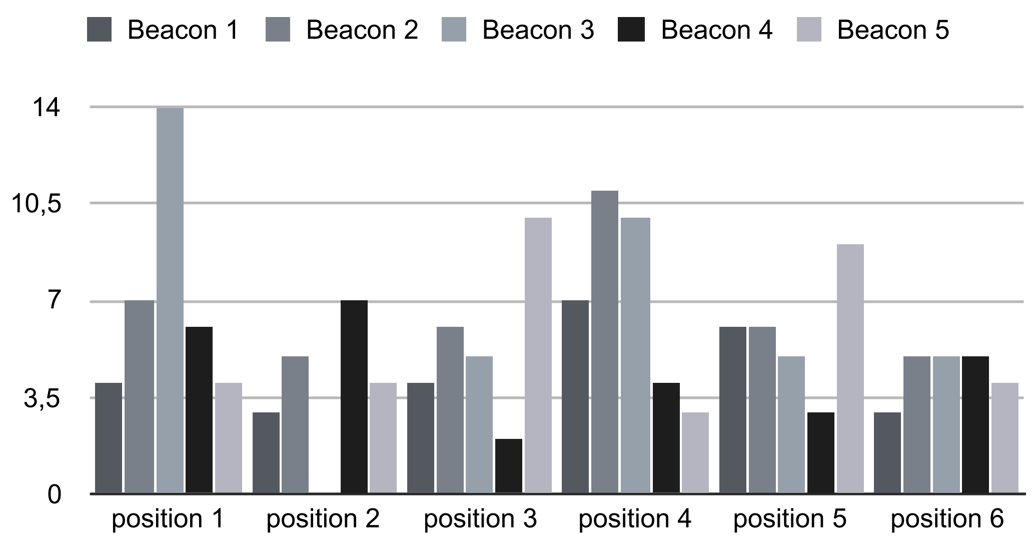

Figure 15. Difference between maximums and minimums of RSSI values from each beacon per position.

The best-case scenario from this test can be found from beacon 4 at position 3 with a difference in RSSI value of 2 points that translate to a distance discrepancy of 0.5m. By the results founded here the average discrepancy of the same signal received from the same beacon at the same point is of 5.76 RSSI points. This means, that in contrast to the results obtained in the iBeacon proximity method, the signal received by a device at any point is not reliable to a fine grade. Multiple readings need to be take into account to get more accurate measurement.

5.1.2.2. Measured Signal Vs Actual Distance

At this point, this study analysed the accuracy of the given derived distances from the RSSI by the iBeacon and compare with the actual measured distances from the positions to the beacons on the room. As shown in figure 16.

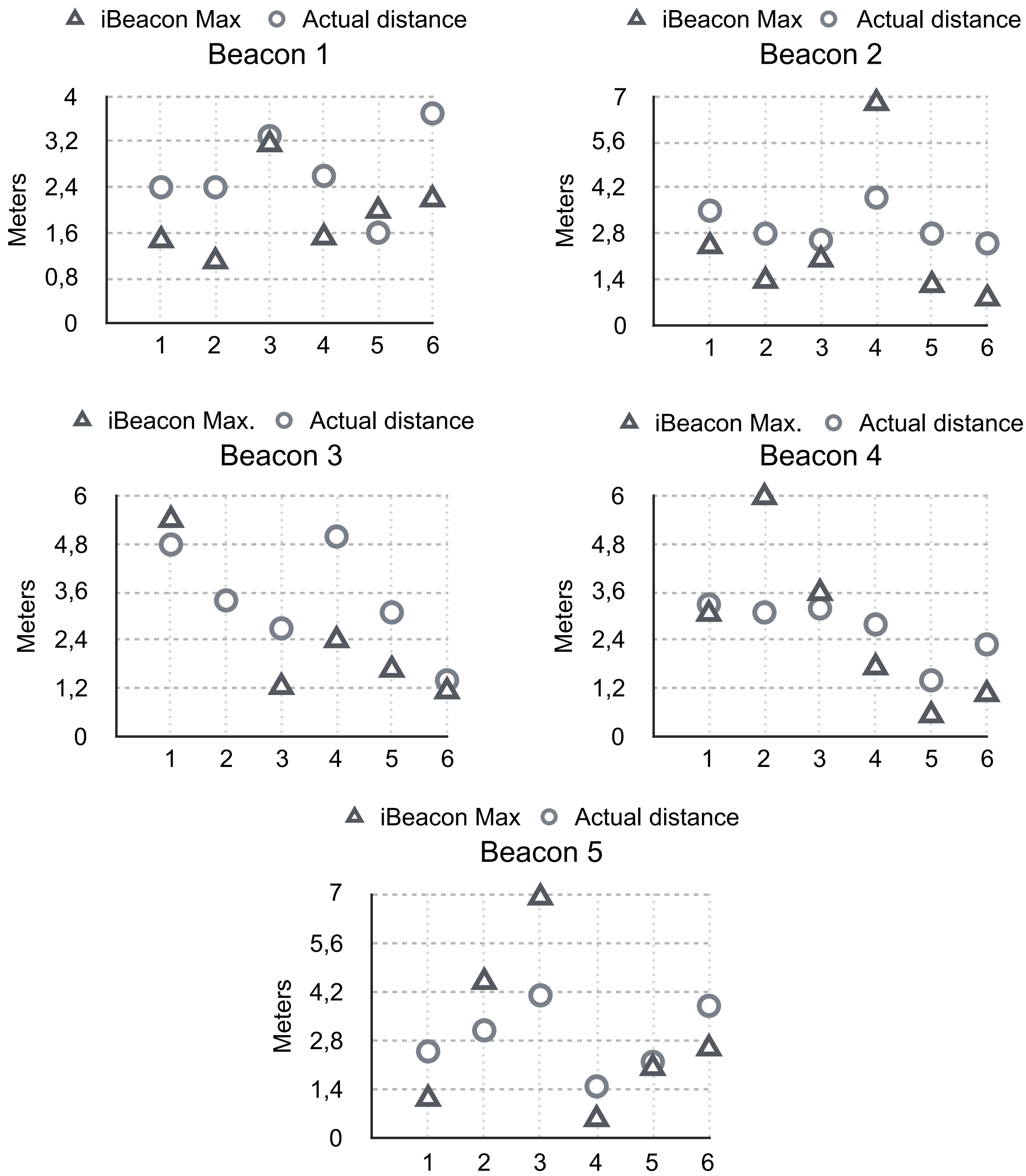

Figure 16. Relations between the beacons distance returned from the iBeacon (maximum value) and the actual measured distance.

These test results show that the maximum values showed to be the closest one to the actual distances. For that reason, the used value as the measured point was the maximum value. This was done in order to simplify what values were assigned to the beacons.

More testing and particle filtering algorithms could improve the results of the values assigned to the beacons. The most common case encountered by this test is that the maximum value returned by the iBeacon is under the actual distance. There were a few cases where the minimum value or average was closer to the actual distance.

The accuracy of the measured distance obtained from RSSI value from a single beacon is not reliable alone. In the best case of accuracy found on the test showed an error of 0.14m and in the worst case was over 3m. Of course, these results are from each beacon alone, In the next point this study looked into the results of the combined results.

5.1.2.3. Trilateration Results

Up to this point, this study was analysing the reliability of the measurement from each beacon. In this part, the results of the combined signals were analysed to see if the desired results could be obtained with this method. As shown in figure 17. When the signals were combined the test shows that the accuracy is not reliable with the number of beacons used in this particular room for all the positions.

Never the less if we look at the results of each position some additional conclusions can be drawn. Position 2 showed that when the results of one particular beacon are off in comparison with the other beacons results or by giving a distance value greater than the actual space that it would decrease the accuracy greatly. This value can be drop as an error and used the average value instead. This way it can be filtered out the beacons that are having greater interfering. This was done on the measured value from beacon was longer than the actual distance it could have been inside the room.

In position 2 for the above described reason was to drop the maximum value and added the average value of the measurements instead of beacon 4. This helped to reduce the error considerably. In this position also one of the beacons was not included in the array (probably due to some interference) For that reason the position was only measured with only four beacons. In comparison with the other measurements, it gave lower accuracy as the possible location extended over a longer radius than in other similar positions, as in position 3. Even though the radius of possible locations was bigger than the locations gave by larger beacon array the area was mostly spread on

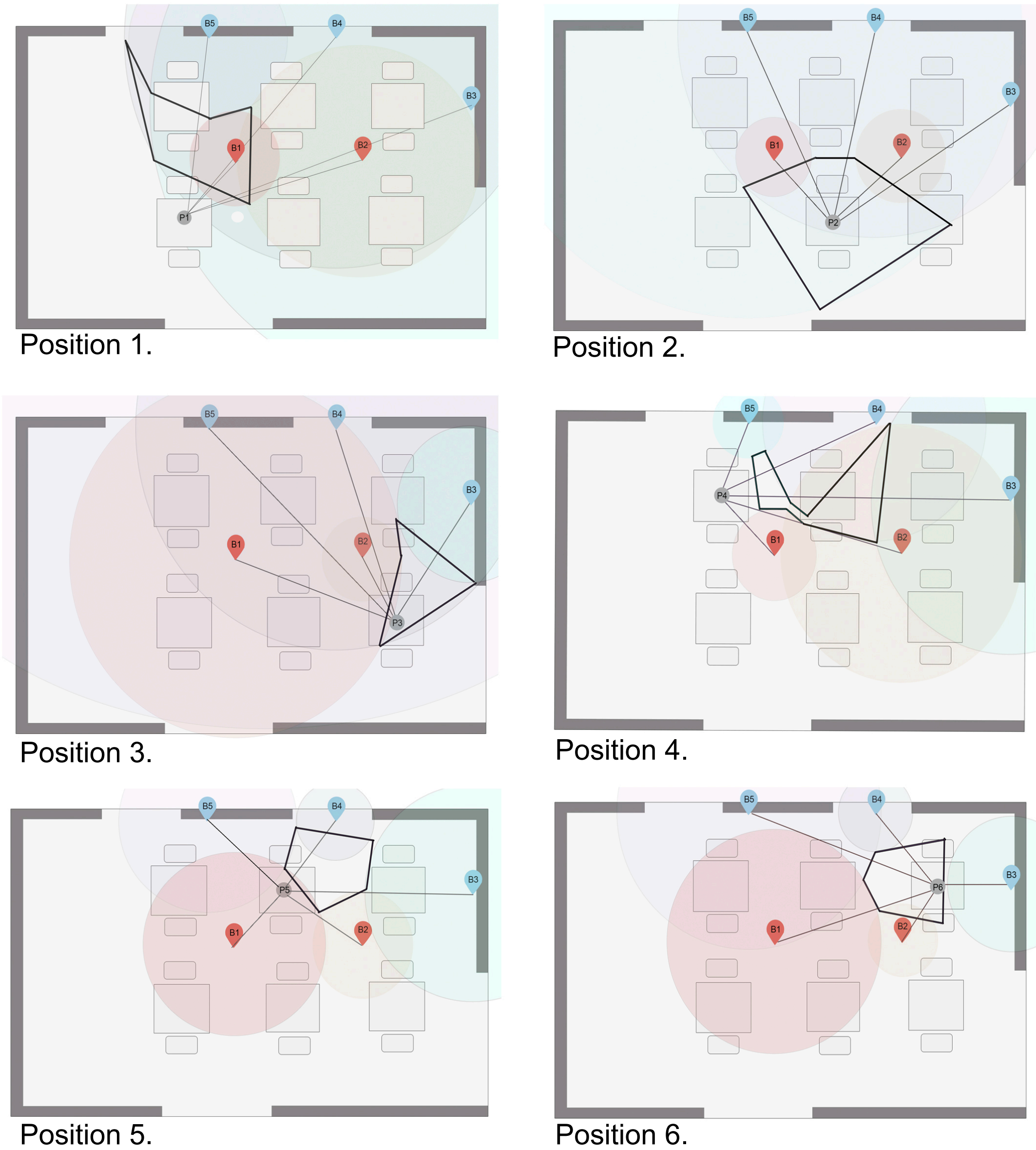

Figure 17. Graphic representation of the trilateration results of the different positions.

the correct location thanks to the corrections made.

In the cases where the beacons surrounded the measured position (positions 5 and 6) were found by this study to be the most accurate ones. These positions also gave similar levels of accuracy. One possible reason is that when measuring from one location that the beacons are placed only on one side the errors this my have do not cancel out. But when the location measure is surrounded by beacons, or not only in one of the sides of the beacon, it helps considerably to decrease the error of each individual beacon. The distance from the device and the beacons seem to affect as well; smaller distances seem to give more accuracy. The topography of the room and how the beacons are placed on this one seems to have great effects.

5.1.2.4. Beyond the Results

Overall these results showed that could be possible to use this method for table location in indoor places but more beacons are needed per location to increase reliability and algorithms to improve the results.

In this test, the study compared the results of the iBeacons values in contrast with the actual distances from the measured position and the beacons. Another possibility is to use fingerprinting. This is carried out by mapping the results obtained from the beacons at different positions on the map and analysing the reading signals from the beacons in contrast with the created map.

6. CONCLUSION

The scoop of this study was to analyse the possibility of using Bluetooth Low Energy Beacon to locate customers in an indoor location to assign a specific table. With the use of iBeacon proximity the tests carried out by this study were successful. Furthermore, this technique is was found to be easy to implement and maintain and requires less planification and beacons than the trilateration approach.

The trilateration technics tested in this research were found to be less reliable than the iBeacon proximity technic. Trilateration seems to be more useful for routing or general location inside some space. It was found several disadvantages with this approach. It requires a larger number of beacons for the same amount of space, in most cases. The installation and maintenance of the beacons seem to be more complex and difficult to access; beacons need to be placed in strategic places and in places clear of obstacles. For this approach to work better more careful planning is required when setting up the beacon network. In the software side requires the implementation of more complex algorithms to increase the accuracy. One of the main negative points of this approach is that in the case of the tables been move the system needs to be updated this is also the main drawback of the fingerprinting technics.

Even though, Fingerprinting technics were no directly tested by this study from the trilateration test is possible to how the signal instability can potentially lower the accuracy of this technic. Most restaurants rearrange tables at some point for different reasons, those changes on table positions would render the system useless and it would require to be updated.

This study could not test any of the systems with a large amount of people at the location but the test showed that the signal was decreased by objects or people placed between the beacon and the receiver. With these assumptions and by the data obtained on the tests that were made. The iBeacon proximity technic had a clear advantage over the trilateration approach in the case of indoor table location. Since the people will interfere more with the signals coming from a beacon in other tables than the signal from the table where the device is located, this tends to be the more intense one. On the other hand, with trilateration interference on the signals would just decrease the accuracy of the whole system.

It can be also possible to use the combination of multiple technics and technologies in cases where more complex requirements. For example table location and routing.

Different beacons could be assign to different networks to be use with different technics with in the same application. But the combination of multiple approaches falls out of the scope of this study.

Over all, from the results obtained on the tests carried out by this study and the general advantages on setup, deployment and maintenance. The conclusion of this thesis is that is possible to obtain accurate enough indoor location for table assignment with the use of Bluetooth Low Energy Beacons and iBeacon Proximity technics.

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