The application of Beacon technology in the festival industry

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Abstract

Beacons are an emerging technology contributing to the Internet of Things, their intended function is to provide indoor proximity detection utilising Bluetooth Low Energy as a means of communication. The purpose of this investigation is to determine if beacons are a viable technology for a festival environment, considering hardware and software capabilities, exploring possible festival targeted applications and developing a beacon powered mobile app to a professional standard. Their exist many opportunities for beacon integration within a festival environment for assisting both festivalgoers and event organisers, such as providing live queuing times for food courts or offering navigational assistance throughout the festival grounds. It was found that beacons are a viable technology, when used for their intended purpose. They lack accuracy, particularly at range, though when used to determine proximity they were found to be very effective, as supported by the UCAS tour guide demonstration. The simplicity of beacon technology provides a simple platform for developing intricate, contextually aware applications aimed at improving the festival experience for providers and consumers alike.

Acknowledgements

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Table of Contents

Section 1: Introduction

1.1 Overview

Pervasive computing is a term used to describe the embedding of technology into everything and anything. Since Mark Weiser's ubiquitous computing vision in 1991, contextually aware, location-based applications have become more and more commonplace. Pervasive computing is becoming more popular, embedding networked processors and sensors into multitudes of objects and devices.

BLE (Bluetooth low Energy[1]) is a key emerging technology enabling device-to-device communications. BLE has been developed for increased energy efficiency and transmission range, sacrificing bandwidth from previous Bluetooth technologies to achieve this. This will be discussed further in section 2.1. The following is taken from bluetooth.com (Bluetooth).

Bluetooth Smart features provides:

- Ultra-low peak, average and idle mode power consumption
- Ability to run for years on standard coin-cell batteries
- Lower implementation costs
- Multi-vendor interoperability
- Enhanced range

BLE is helping to power connectivity for "more than 10 billion wirelessly connected devices in the market today; with over 30 billion devices expected by 2020." (ABIresearch 2013) Examples such as Smart Phones, Tablets, Heart-rate monitors, Proximity sensors and Smart watches.

Beacons are another example; a compact, inexpensive, BLE transmitting device designed to facilitate location-based applications and services. This technology allows mobile devices to trigger actions associated with the beacons ID whilst within the designated beacon proximity.

Beacons are already being utilised in many different ways for many purposes; for instance:

- Location specific advertisement – primarily benefiting retailers with a more specific and targeted approach to marketing.
- Home automation – simplifying home living by automating commonly executed tasks such as turning on lights, opening blinds, etc.
- Indoor mapping and guide – can be used to aid disabled or visually impaired people. Or as a smart map, detailing current location and fastest routes to desired places.
- Door / Barrier entry – beneficial to crowded venues, where efficient barrier entry is essential. Added security could also benefit with encrypted tickets activated upon beacon contact, being impossible to counterfeit.

[1] Also referred to as Bluetooth Smart / Bluetooth 4.0

- Automated payments – proximity based mobile payments could remove the need for queues and checkout type POS systems.

Currently, the primary application for beacons is in the retail sector. An example of this is House of Fraser, a UK retailer, who announced plans in 2014 to incorporate beacons into their Aberdeen store's manikins, providing customers with a more enriching retail experience. The House of Fraser app can provide manikin specific information about the clothes and accessories displayed, their in-store locations and even a direct link to purchase from the retailers website. (Skinner 2014)

Beacons have also been introduced to other sectors, such as galleries and museums. Beacons can enhance the customer experience, offering extra information for exhibits or even a location aware audio guide. For instance, the Welsh National Slate Museum is enhancing their museum tours through the use of beacons by placing 25 throughout the museum. The application enabled by these beacons offers contextual text, images, audio and video as extras to the historical experience. David Anderson, Director General, National Museum Wales shared his thoughts:

> "This initiative is a game-changer. It takes the use of technology in museums to a higher level . . . we are exploring the full potential of this technology to create a new world of public services for the cultural, heritage and museum sectors." (National Museum Wales 2015)

As seen here, beacons are making an incredible impact for a diverse array of environments. They are being favourably received and show potential for revolutionising many aspects of society. This report details an investigation into the potential effectiveness of beacons in festival environments; determining opportunities for beacon applications, evaluating hardware & software limitations, assessing consumer feedback and exploring beacon development.

1.2 Investigation scope

The original scope for this investigation proposed investigating the entertainments industry as a whole, to include festivals, theme parks, arenas etc. However, this was reduced because the project's time constraints would not permit such a broad scope.

This scope has been limited to only festivals, as a festival environment is radically different to that of retail, museums or other current beacon enabled environments. A festival is the most extreme environment where there is also opportunity for beacon integration. Festivals offer a tremendous amount of consumers, unknown weather conditions, wide-ranging confusion and huge expanses of space. This leads to many opportunities for both festivalgoers and event organisers.

For the festivalgoers, beacon deployment could enhance their overall experience and assist with overcoming the festival commotion.
Some example opportunities include:

- Navigation assistance throughout the site – compared to a paper map, a beacon-enabled mobile app could pinpoint a users location and provide the fastest route to their required destination taking into account crowd densities.

- Current and future performance notifications – a festivalgoer may not know what stage they are next to, or who is playing. This information is not usually readily available. The notification could draw attendees to smaller stages, dissipating the larger crowds.

- Venue capacity information –could help festivalgoers decide which stage they want to see before even leaving the tent; saving valuable time navigating the festival and minimising congested areas where consumers are deciding which stage to view.

- Promotional offers - it can be difficult to view promotional offers and prices next to crowded stalls and vans. A user could view prices for a given outlet on their mobile device from several metres away.

- Live queue times for toilets, food outlets, bars and access gates – knowing which queue is the smallest before trekking across a festival could save valuable time. This information would be otherwise unknown, until the festivalgoer see's the queue and even then, an accurate waiting time is unknown.

For festival organisers there is opportunity to gather valuable data such as:

- Staff locations and movement – festivals can have hundreds of temporary staff. Ensuring staff members are performing their assigned task and evenly spread across the festival could increase productivity.

- Crowd bottlenecks – by monitoring crowd densities, event organisers can better design festival infrastructure in future years to provide better access throughout.

- Venue capacities – beneficial to security staff, health and safety services and for accurate venue statistics.

- Most / least popular attractions – organisers can use this information to better tailor future festivals.

Currently, there exist many beacon manufactures, all-competing for market domination. Given the time constraints for this investigation, an analysis of multiple beacon providers would be impractical. For this reason, the investigation will focus solely on Estimote beacons. Estimote is the largest and most prominent manufacturer in the beacon industry. By using Estimote (whom is most likely to become the staple beacon supplier), I maximise the potential for this investigation to be relevant and beneficial in the future.

1.3 Objectives

This investigation's primary objective is to determine *whether beacons are a viable technology for a festival environment.* This can be broken down into four sub-objectives:

- To explore beacon characteristics, evaluating their limitations and strengths.
- To thoroughly test the beacons and determine their physical capabilities.
- To assess the general publics opinion surrounding beacon technology.
- To explore opportunities for innovative contextually aware applications in a festival environment.

My primary objective will be supported by two further objectives:

- To research current Beacon-enabled services, applications and locations; evaluating their effectiveness, and relating their underlying methodologies to a festival environment.
- To acquire direct experience developing a professional beacon-enabled Android application. Released to the Google Play store and utilised as a field study to investigate the effectiveness of beacons in a real-world application, furthermore assessing user interaction and opinions surrounding beacon technology.

Section 2: Background

2.1 History

The term "beacon" commonly signifies a large deliberately conspicuous object used to draw attention, such as a lighthouse or signal fire. A beacon relevant to this investigation is quite dissimilar. A small, unobtrusive gadget used to inform any BLE supporting device of its location and identification values, powered by a single coin cell battery for up to two years.

The underlying technology powering beacons is BLE. Nokia developed BLE in 2001, it was finalised in 2006 and introduced under the name Wibree. (Genuth). Not until 2010 was Wibree merged into the main Bluetooth brand with the adoption of the Bluetooth Core Specification Version 4.0. In October 2011 the iPhone 4S was released – the first device to implement this new technology. From this point BLE gradually became the standard for all commercial mobile devices.

BLE is not the only mobile to mobile communication technology. NFC (Near Field Communication), Wi-Fi and Zigbee are all competitors in the wireless communications market. NFC is a relatively new technology enabling the wireless exchange of data between devices up to 10cm apart. This technology is primarily aimed at mobile devices and has such functionality as contactless payments and device pairing. (Kremer) Wi-Fi is the international standard device to network technology, designed for large data transfer using high-speed throughput. It can handle up to a 300Mbs bandwidth. Though it is an efficient wireless technology, it is not designed for coin cell operation like BLE, or Zigbee. Zigbee is the most similar to BLE, established in 2002 and targeted at home automation, smart meters and remote control units. It works by mesh networking low power Zigbee devices to create a personal area network. Zigbee transmission distance is 10-100m; using a mesh network this distance can be infinite. "Unfortunately, ZigBee's complexity and power requirements do not make it particularly suitable for unmaintained devices that need to operate for extensive periods from a limited power source." (Smith 2011) Due to this, BLE became the standard beacon communication technology.

2.2 Industry

Beacon manufacturers have exploded into the technology industry in recent years; offering a whole host of beacon hardware, SDK's, customisations and packages. It is clear that beacon technology is going to contribute greatly to the consumer experience over the next few years, making this emerging market very competitive.

When choosing a beacon provider for this investigation it was essential the company had the following characteristics:

- An established and supported brand to maximise the influence of this investigation.

- A thorough and well-documented SDK to aid with the short deadline development projects.

- A strong developer following to maximise the influence of this investigation; additionally to provide support and 3rd party knowledge surrounding the given provider.

- Large-scale deployments utilising the hardware for research purposes, as it is impractical for this investigation to directly test large implementations.

- The product must have a durable and water-proof outer casing able to withstand poor weather conditions.

The first "beacon" type product assessed was the Air Cable Mini. It has a simple design (see Figure 1), is relatively cheap to purchase and is fully configurable due to its BASIC[2] application code. (Air Cable). The primary drawback to this product is the lack of BLE support, relying on Bluetooth 2.1 a much more power draining communication technology.

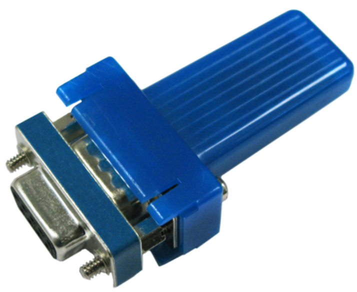

Figure 1: Air Cable Mini

Bluetooth 2.1 is not appropriate for beacon-enabled applications due to the increased power draw and decreased range. The Air Cable Mini does not provide an SDK, or have a strong developer following. For these reasons the Mini was rejected from this investigation.

Figure 2: Kontakt beacons

The second company investigated was Kontakt – a Poland based start up, founded in 2013 with the aim of helping "the visually impaired navigate public spaces more easily". (Kontakt.io) They are now one of the industry leaders in Beacon hardware and software. They offer an open source Android and iOS SDK however the Android SDK is much less developed. Their developer community is limited compared to other Beacon manufacturers and online resources are scarce. Their beacon comprises of a 55mm x 55mm x 15mm waterproof case, containing a 32-bit ARM CPU, 256kb flash memory and 16kb RAM with a transmission range of up to 70m and a battery life of up to two years. These specifications are relatively standard for the primary beacon manufacturers. The distinctive element for Kontakt is the option to aesthetically customise the beacon with a personal logo, text and colour. Due to Kontakt's limited developer community they were also rejected from the investigation.

[2] BASIC: Beginner's All-purpose Symbolic Instruction Code – a high level programming language designed for ease of use.

Estimote are currently the most widely utilised and deployed beacon manufacturer. They offer an aesthetically pleasing 55mm x 38mm x 18mm waterproof device; housing a 32-bit ARM processor with 256kb flash memory, a transmission range of up to 70m and a battery life of up to two years. Estimote's beacons also include a temperature sensor and accelerometer that can be used to gather further contextual data from the beacon. (Socha 2015) Estimote has so far distributed 10,000 developer kits[3] leading to a large, active developer community with many online resources available. There are several successful, large-scale applications utilising Estimote beacons. For instance, Toronto Eaton Centre has installed 180 Estimote beacons across four floors to enhance visitor experience. (Borowicz 2014). Primarily, due to Estimote's industry standing and large developer following, this investigation will use Estimote hardware and SDK, for all developing and testing situations.

Figure 3: Exploded Estimote beacon

2.3 Beacon technology

Estimote beacons are implemented using relatively simple technological concepts. A beacon consists of a small ARM computer, powered by a battery that continually 'pings' BLE packets in a spherical area surrounding the beacon. (Estimote 2015) This packet can then be intercepted and interpreted by any BLE supporting device. An example packet can be seen in Figure 4. (Warski 2014)

```
1 02 01 06 1A FF 4C 00 02 15 B9 40 7F 30 F5 F8
  46 6E AF F9 25 55 6B 57 FE 6D 00 49 00 0A C5
```

Figure 4: Estimote beacon, BLE packet example

This 30-byte packet fits nicely within the 31-byte BLE limit. The packet consists of the BLE beacon prefix, proximity UUID, Major, Minor and Tx values. See Figure 5 for diagram.

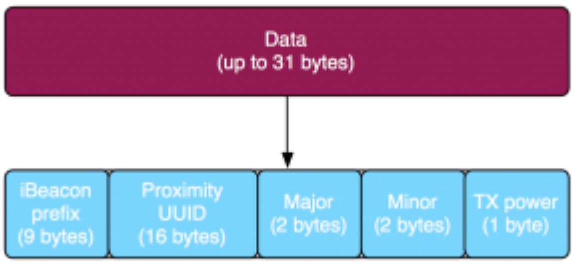

Figure 5: BLE beacon packet diagram

The receiving device determines the identity of the packet using the beacon prefix. The proximity UUID, Major and Minor values are all configurable and used to identify the beacon. Tx power is used to determine how close the device is from the beacon. It is the strength of the signal measured at a 1m distance from the device, or more commonly referred to as RSSI – Received Signal Strength Indicator. Knowing the RSSI and the currently received Tx,

[3] A developer kit consists of three Estimote beacons and access to the Estimote API

(current Tx is acquired from the received signal) it is possible to calculate the approximate distance from the beacon to the received device.

Once the device has interpreted the data packet, an application installed on the device can determine what beacon the device is closest too relative to the Major and Minor values. These values can be customised unreservedly, though the intended use is to assign a large area to the Major value, for instance a retail branch. Individual sub-areas, such as an individual department or isle, would be assigned a minor value. For example a retail store may have 4 departments with 10 beacons in each. The application could assign the Men's department a Major value of 4, with each beacon being assigned a value 1 – 10. The Proximity UUID is used to distinguish sets of beacons; an application cannot discover an Estimote beacon without knowing the UUID.

Once the application recognises the closest beacon, a trigger can be executed for any number of actions. For example:

- Pulling an advertisement from a server and displaying on the UI.
- Recording beacon values and current time to create a log of user movement.
- Activating and authenticating a digital ticket.
- Updating a server with the devices current location before informing all "friend" devices of your location.

Note: Beacons can only be used to trigger events on a mobile device; they are unable to deliver content.

2.4 Estimote SDK

Estimote offers a relatively basic library for interaction between Estimote beacons and Android devices. The SDK requires Android 4.3 or above and a BLE supported device. The library allows for beacon ranging, monitoring and characteristic reading and writing.

Beacon ranging is used to approximate the distance between the device and nearby beacons. This information could be used to determine where a device is relative to multiple beacons, or to trigger an action specific to the nearest beacon. As BLE relies on radio signals, accuracy will vary dependent on the environment and if any obstructions are present. (See section 4.2) The `startRanging` method from the BeaconManager class continually searches for beacon transmissions. A listener object, registered with the `setRangingListener` method, updates once a second with a list of currently found beacons. This list can be iterated through and interpreted for required data.

Beacon monitoring is used to determine when a device is in proximity of a beacons region. Monitoring is designed to perform periodic scans. The period is configurable, but the default scan is for 1 second before waiting for 25. Applications can use the `startMonitoring` method from the BeaconManager class to initialise monitoring. `setMonitoringListener` can be called to create a listener for a given region. This listener will automatically call `onEnteredRegion` and `onExitedRegion` respectively when entering or exiting a region.

2.5 Current implementations

Beacons are an emerging technology; nevertheless there already exist many examples of functional, beneficial, full-scale implementations powered by beacons. Beacon technology is primarily being utilised in the retail industry, an example of this is the Swan shopping centre in Eastleigh. They are trying to narrow the gap between classic retail purchases and online shopping by deploying 54 beacons throughout the centre with the intent of welcoming customers and pushing location-based promotions. (Rossi 2014)

Retail is not the only industry beacons are impacting; "Miami International Airport – First of it's kind to become fully beaconized." (ibeacon) This 40 million annual passenger airport has installed beacons throughout, including all entrances, gates, parking zones and baggage carousels. This grants passengers precise, contextually relevant information regarding boarding times, optimal routes to gates and even where their car was parked. This mass rollout of beacon technology in the airport industry will encourage other airports to follow suit, providing an all-round more convenient system for international travellers. Relating to a festival – if an airport environment with thousands of travellers and interfering communication signals can effectively utilise this technology; so should a festival.

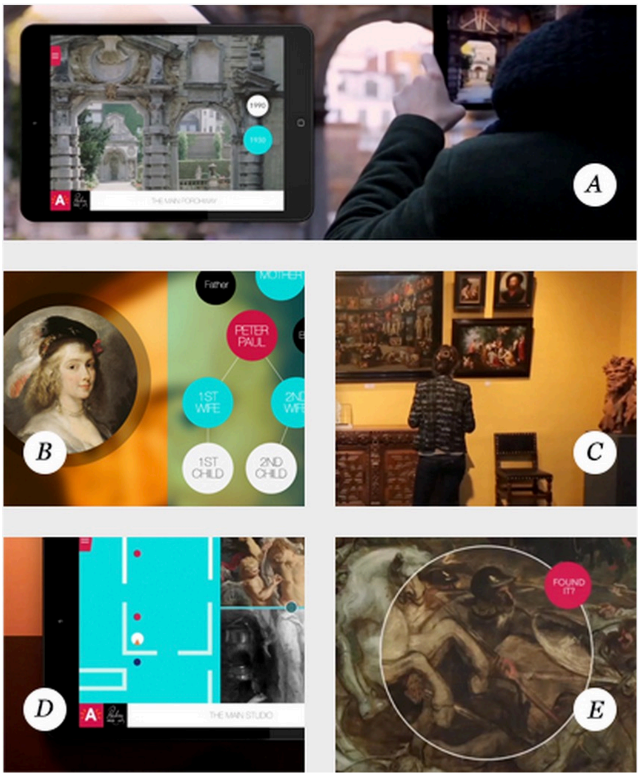

Figure 6 Rubens House Beacon

The Rubens House museum in Belgium, in partnership with Prophets, (a digital agency) has developed an Estimote powered mobile application to revolutionise the museum experience. Prophets has developed an interactive digital tour guide for the museum adding a second dimension to the visitor's experience. (Prophets) Aiming for increased interaction with the exhibits, they have developed small interactive puzzles that trigger when in proximity to an exhibits beacon. Figure 6 and the associated bullet points (taken from the Prophets website) demonstrate some example functionality incorporated into the application

a) In the inner courtyard you discover the history of the porch way. You start from a painted image from the 16th century to a photo from the beginning of the 19th century and pictures from before and after the restoration.

b) Various paintings show you portraits of Rubens´ wives and children. At each work you are asked to place the family member in the right place in the family tree.

c) From a single overview work you go looking for the location of the depicted paintings and images. If you find the right image, the accompanying iBeacon sends you a confirmation.

d) All of the iBeacons in the museum together form an indoor GPS system, with which you can follow a thematic route through the Rubens House.

e) At different paintings you can look at an x-ray scan, zoom in on details, or be asked to answer questions.

Example C from Figure 6 illustrates multiple paintings one of which is accompanied by a beacon interacting with the consumer device. The accuracy required for this level of precise location identification is quite amazing; the apparent success of this beacon deployment (though quite simple) bodes well for a festival context, where beacons could be used for precise location measurements. For instance when establishing if a user has entered / exited a queue, or when passing through an entrance gate.

Section 3: Possible applications

The following section will propose and explore several possible beacon powered applications designed for a festival environment. The merits for both the consumers and producers will be discussed, along with the theoretical application and deployment.

Beacons offer a relatively simple means of gathering contextual data for mobile devices. This simple implementation can form the grounding for some quite intricate and featureful applications, reaching beyond the standard concepts discussed so far. Detailed in the following sections are some application concepts.

3.1 Live queue times

An application where a user can browse a list of queues available during a festival. These queues could be for toilets, bars, food courts, entrance gates, etc. The list would display, live, accurate queue durations based on previous customer queuing durations. A user can select a list element to display further information regarding the selected queue; for instance, a map with directions or (if applicable) user generated reviews. See Figure 7 for an example user interface. The top category bar found in Figure 7 can be horizontally scrollable, enabling any number of categories. The list for each category can be vertically scrollable, permitting hundreds of queues if need be. If the content becomes so vast that manual searching is no longer appropriate a search bar can be added to the application header, or a tab can be added for recent queues – allowing users to lookup their previous queue locations.

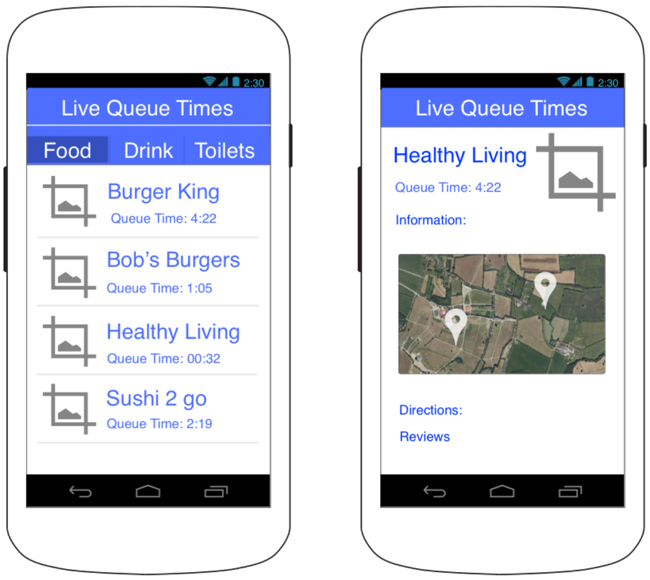

Figure 7: Live queue times UI

The minimum requirements for this application are as follows:

- Server
- 15% of festivalgoers with the relevant app installed
- Android 4.3
- Internet connectivity
- 3 beacons per queue

All queues throughout a festival would register how long a user spends waiting; this value would be inserted into a running average of waiting times for a given queue. This system would work most effectively with a minimum of three beacons. Two placed at the beginning of the queue and one at the end. See Figure 8 to the left. Optional beacons can be added throughout the queue for intermediate readings. For this application to work accurately it is vital that the app only accounts for a user that is genuinely participating in the queue. To certify this, the app must receive a signal from both beacon 1 and beacon 2 simultaneously. As seen in Figure 8, the overlapping of beacon proximities permits only users genuinely entering the queue to trigger the application. Upon receiving both signals, the server will be notified of the users queue entry status and current time. Using two beacons for entry will dismiss many false entries that may occur with just one beacon. To further combat false entries or intermediary exits, a time-out function can be applied to users whom have entered the queue but not exited in a standard time. For this function, it is recommended to have a time-out value proportional to the average queue time. For example, if a user has remained in the queue for 5 times the average value then remove their queue entry status. Secondly, if a user is classed as entered queue 1 but then triggers the entry for queue 2 – switch their status to entered queue 2. False entries can be avoided completely given the design of Figure 8, and thorough distance testing of beacons 1 & 2.

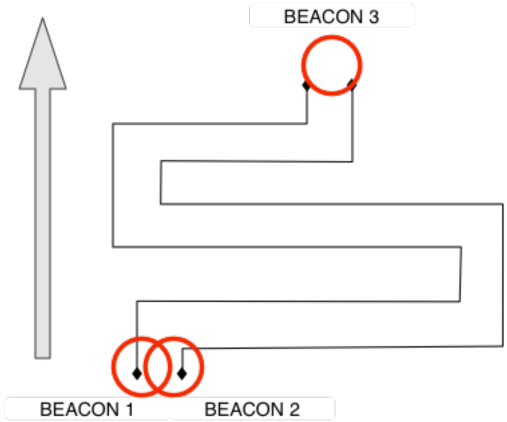

Figure 8: Implementation diagram for live queue times

To exit a queue a user must receive the signal from Beacon 3 and have 'queue entered' status. Beacon 3 can only trigger an application that has already been triggered by beacons 1 & 2. This can be verified either locally by the device keeping a record of what beacons have been triggered, or with a lookup to the server checking if the user has entered the relevant queue. Once a user passes through beacon 3 the app will notify the server of the users queue exit status and the current time. The server can then deduct the exit time from the entrance time to find the time spent in the queue. From here, it is recommended to calculate a running average of queue participant times to remove anomalies. This data can then update the relevant list element for every application in the festival.

The 15% minimum app installs requirement is to ensure accuracy of queue times. As the server will only update the queues time average when a registered user exits the queue; it is important that a certain percentage of people in the queue are being tracked.

3.2 Advertisement

Location-based advertisement is the most common application for beacons; however, it is also worth mentioning here, for a festival. A large part of the 'festival experience' is the stalls and merchants, offering a wide array of food, beverages and merchandise from all over the world. There is great competition between traders for commercialising the hordes of festivalgoers, Glastonbury festival can have more than "170,000 people on site at the busiest" (Glastonbury Festival 2014).

Currently, merchant advertising is restricted to physical signs and banners on the traders pitch. Beacons could offer a much more targeted and effective method of advertisement. The simplest approach is to have one beacon per merchant, so when a device recognises the beacon a notification is displayed advertising the recognised merchant. Ideally this would be accomplished in collaboration with the given festivals' mobile application. This concept could be made more intelligent however; advertisements could promote merchants given the current context. For example, if it is approaching lunchtime and the user is within walking distance of a food vendor with a small queue – the app could promote this vendor with details of menu, promotions, location and queue times. The festival could offer this service as an optional extra for traders, alongside the cost of pitch for the duration of the festival.

3.3 Interactive map

Thanks to the power of Google's comprehensive maps API, interactive maps are becoming more and more commonplace with many different applications. The Google Maps Android API v2 offers a simple interface for displaying interactive maps within Android applications. (developers.google) The API offers methods for limiting UI interaction with the map, which allows the application to display a map for precise festival coordinates. The API also offers a class called GroundOverlay that provides functionality to overlay the map with an image at specified coordinates, meaning that the overlaid images will zoom and pan with the map when interacted with by the user. These overlaid images can be given click listeners to trigger further actions when the image is clicked. See Figure 9 for example.

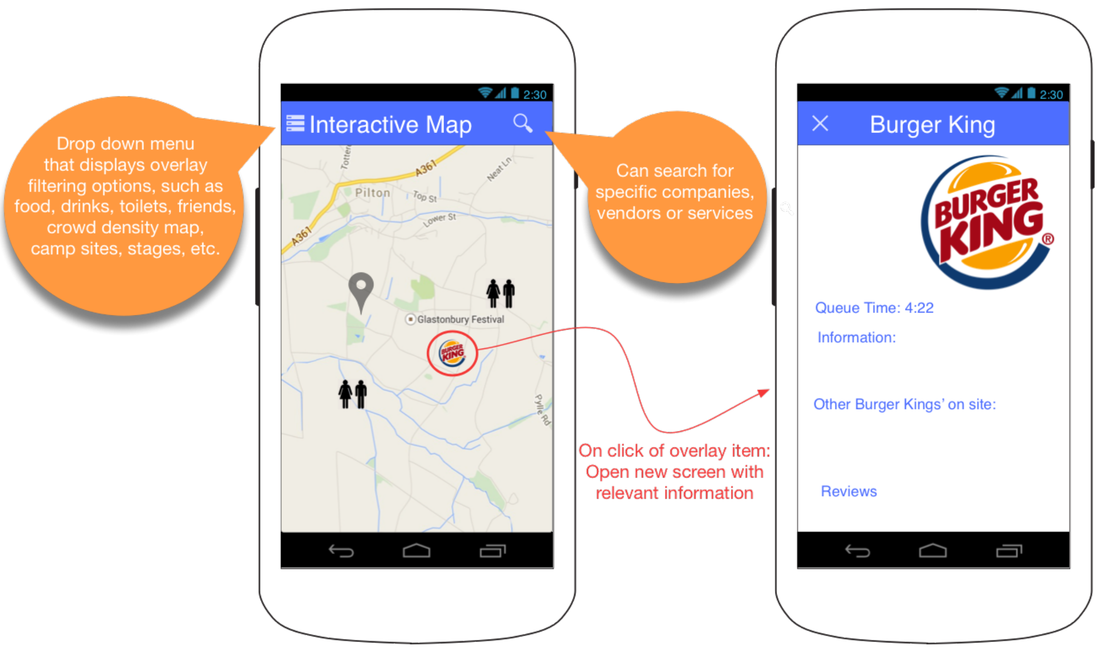

Figure 9: Interactive map example

For this feature to work effectively a stable Internet connection is required. Google do not allow maps to be cached for offline use, therefore the map will be unavailable unless the device can communicate with the Google servers. In the case of an unstable or no connection, beacons can be used to estimate a users location through the use of trilateration[4]; data can then be plotted on a static map image.

Beacons can be used to provide location data relative to the user, this is also possible using GPS. However, BLE uses significantly less power keeping track of a users location than that of GPS. At a festival where power supplies are uncommon, this application's power consumption must remain low. A device can keep track of a users location by forming a digital map of their experience through the beacon signals they have received.

An interactive map could form the backbone of a festival map. Providing one interface that offers a whole host of features valuable to a festivalgoer. Features such as:

- Find current location
- Find past locations
- Track location in a festival over time
- View current and upcoming performances
- Find tent location
- Search for a specific place

This application could also work socially. A search could be performed of a user's Facebook friends for other users with the app installed. These users could opt-in to keep track of each throughout the festival providing convenient friend-finding functionality.

3.4 Heat map

A heat map, or crowd density map, could be beneficial to festival organisers and medical personnel. For the later, the ability to assess live crowd densities for the entire site would help significantly when responding to an emergency. The medics could plan their route, avoiding the most dense areas to minimise travel time and alleviate hindrances. Medical personnel could be positioned in proximity to the densest areas; these areas are most likely the origin for many callouts.

Festival organisers could use this data to improve designs for future festivals. Through informative organisation, crowds could be dispersed across the site, improving crowd flow and providing an all-round better experience for attendees and staff.

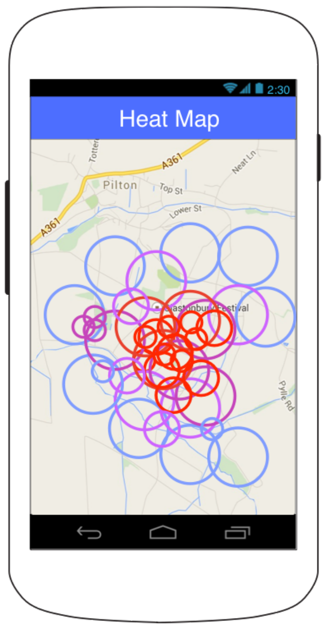

Figure 10: Heat map example

Figure 10 presents an example heat map interfaced from a mobile application. The circles are displayed as

[4] Trilateration is the process of determining relative location based on the known coordinates of at least three other points.

an overlay of the Google maps API, similar to the implementation of the interactive map. (Section 3.3) Beacon ranges are displayed as coloured circles. The colour of the circle indicates the current crowd density and displays the circumference size for the given beacons region.

The implementation behind an application such as this is quite simple. A database of beacons, their coordinates and radius' can be recorded. This will be used to populate the UI with proximity objects. When a device enters or exits a beacon region, the server is informed and appropriately increases/decreases the level of devices currently registered. From here, a density value for a given beacon range can be calculated using Equation (1) below:[5]

$$Crowd\ density = \frac{Number\ of\ devices\ in\ beacon\ range}{\pi r^2} \quad (1)$$

Calculating the densities for every beacon and storing the output in a sorted list would enable beacons to be assigned colours relative to all beacon densities. For example, beacons could be assigned blue, green, yellow, orange or red with the lowest density being blue and the highest red. This would facilitate an efficient and recognizable interface for determining densities within the festival.

Following the calculation of crowd density, the application can be updated periodically with the latest data. The UI can then be refreshed automatically as data is downloaded.

[5] Where 'r' is the radius of the beacon's range

Section 4: Potential issues

The following section will investigate potential issues Estimote beacons may have, given a festival environment. Thorough analysis will be conducted into the capabilities of the hardware and how to maximise the accuracy and range of the beacons.

4.1 Accuracy

Understanding how Estimote determines the distance from a device to a beacon and the level of accuracy this value has is of great importance when positioning beacons and determining their range.

Estimote can approximate the distance from a beacon to a device using the RSSI[6] value found in a beacon packet. (See Section 2.3 for details) The algorithm they have developed for this is unavailable to the public. Because of this, thorough testing has been conducted to evaluate how accurate beacons really are given a controlled, measured environment. The following section details testing conducted on the Estimote beacons with varying distances, power output and advertising intervals.

To ensure a fair comparison across all tests the following variables remained constant:

- The same mobile device was used. (HTC One M9)
- All testing was conducted in the same corridor with clear line of sight
- A test application logged all signals received for 30 seconds, performing one scan per second

The full results from this test can be found in Appendix A. For clear visualisation and easy handling of this large data set, box charts have been used (Figure 10, 11, 12 and 13). The elements of a box plot exhibit the minimum, 25 percentile, median, 75 percentile and maximum values (from base whisker to top whisker). The categories for each plot refer to nine beacon configurations offering a broad but feasible range for testing purposes. Weak, Normal and Strong refers to the power output for the given configuration.

- Weak is -20dBm with a maximum range of 3.5m.
- Normal is -12dBm with a maximum range of 15m.
- Strong is 4dBm with a maximum range of 70m.

The second property for each configuration is the 'ping' interval of the beacon set to 100ms, 500ms, and 1000ms for Short, Medium and Long respectively.

To summarise the results, the algorithm used to calculate distance is not very accurate while the device has a clear line of sight to the beacon. Most distances from 0.5 to 10 metres are calculated 25-75% further than the actual distance. This may have been done intentionally, as with a real-world application it would be rare to have direct line of sight. Estimote may have incorporated this variable into their distance-calculating algorithm.

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[6] RSSI: Received Signal Strength Indicator – also referred to as Tx Power.

That said, there are examples of very accurate results; for instance a beacon placed at 0.5m with a normal (-12 dBm) power output and short (100ms) ping interval achieved an average measurement of 0.59m with a standard deviation of just 0.1 (See Figure 11). Given the optimum configurations and a reasonable amount of testing, distance can be accurate to within 25%. This can be seen in Figure 12. This level of accuracy would work well for establishing a devices proximity to a beacon, but not for pinpointing the exact distance.

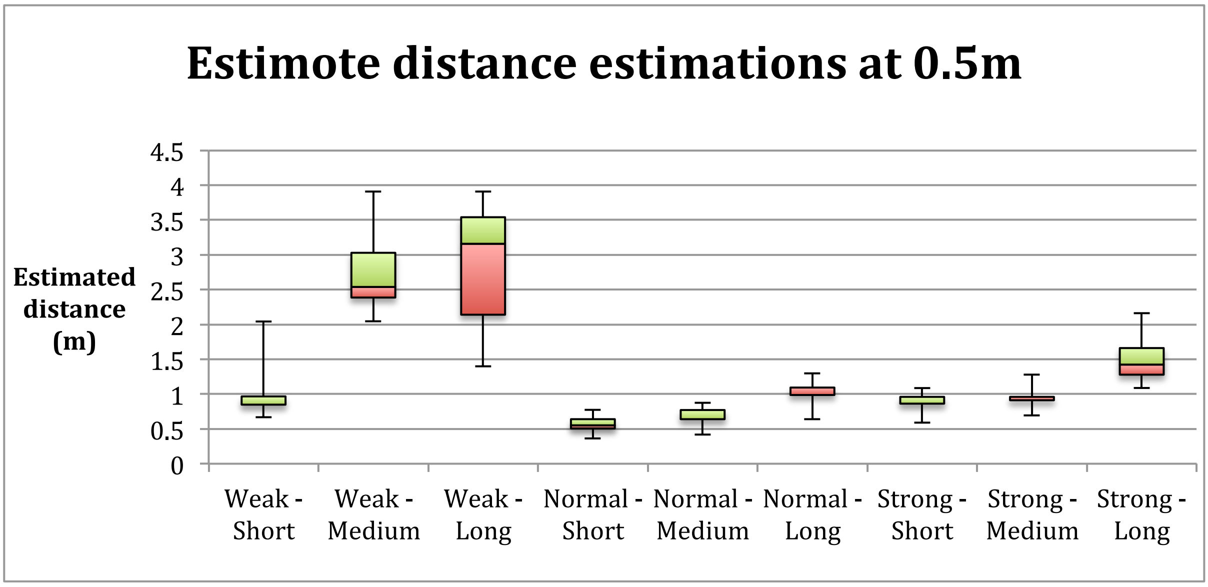

Figure 11: 0.5m accuracy-testing results

Noticeable in Figure 12 is the 20 metres anomaly (this reading was the best of all configurations for 20m tests). When measuring at 20m the returned estimations were 2.5 times greater than the actual distance. It is not clear why the readings for 20m were so dissimilar to the rest of the testing, it can only be stated that radio waves can be unpredictable and this must be noted when attempting to calculate distances based on the RSSI.

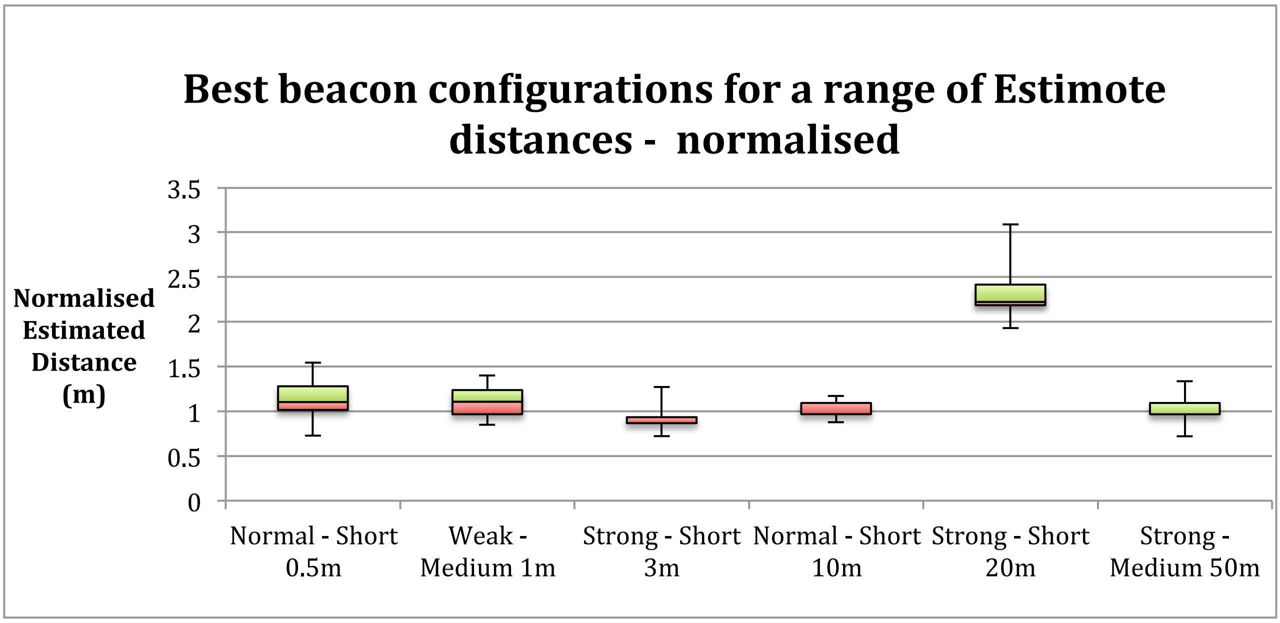

Figure 12: Normalised Box chart displaying best results for all accuracy tests

Also notable in Figure 12 is the lack of long (1000ms) ping intervals in the category of best configurations. Configurations with a long ping interval were commonly found to have the largest range of values and typically the worst averages irrespective of the power output. From this, it is deducible that using a short to medium ping interval will increase the accuracy of the readings, though this will negatively affect the battery life of the beacon.

The maximum and minimum values acquired through this testing were occasionally vastly different to the average. For example, when testing the beacon placed at 1 metre with a normal (-12 dBm) power output and short (100ms) ping interval, a maximum value of 9.7m was recorded. (See Figure 13) This was received in a controlled environment with no obstructions. Given a strong signal interfering environment such as a crowded festival, this value could be even more sporadic. With this noted, it would be unreasonable to track a users precise location in real time given an uncontrolled environment. Averages must be taken over time to predict more precise measurements. As seen in Figure 13, the average for this test was 1.3 metres greater than the actual distance. If unrealistic measurements had been filtered out, this value would have been more accurate.

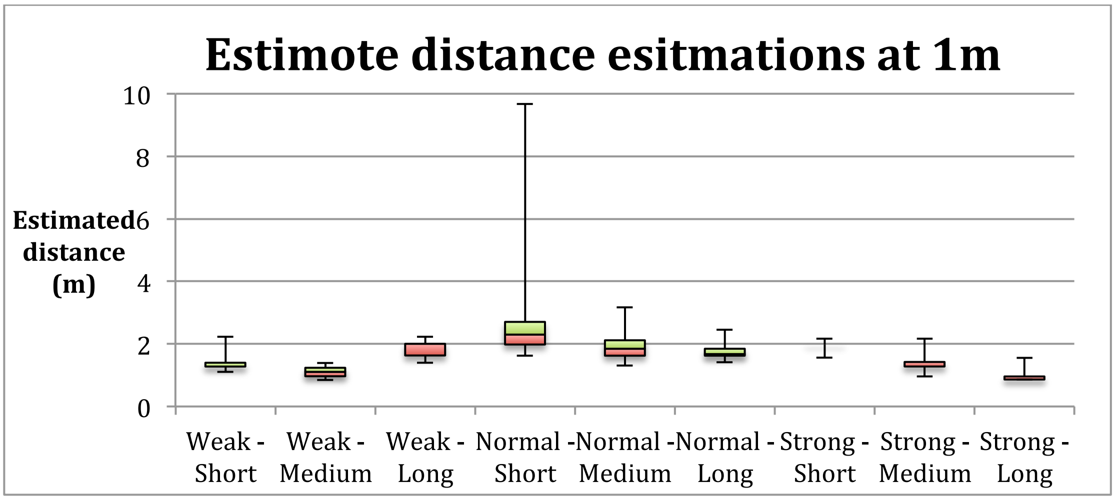

Figure 13: 1m accuracy-testing results

Estimote state their beacons can be recognised at up to 70m. During these controlled experiments it proved difficult to receive any signal at all for a 50m range. The signals received were infrequent and sporadic as seen in Figure 14. Because of this, it is recommended to only have beacons configured for larger regions if the functionality intended for said beacon requires very little consistency or accuracy, for example if a festival wanted to know an approximate number of devices in a field.

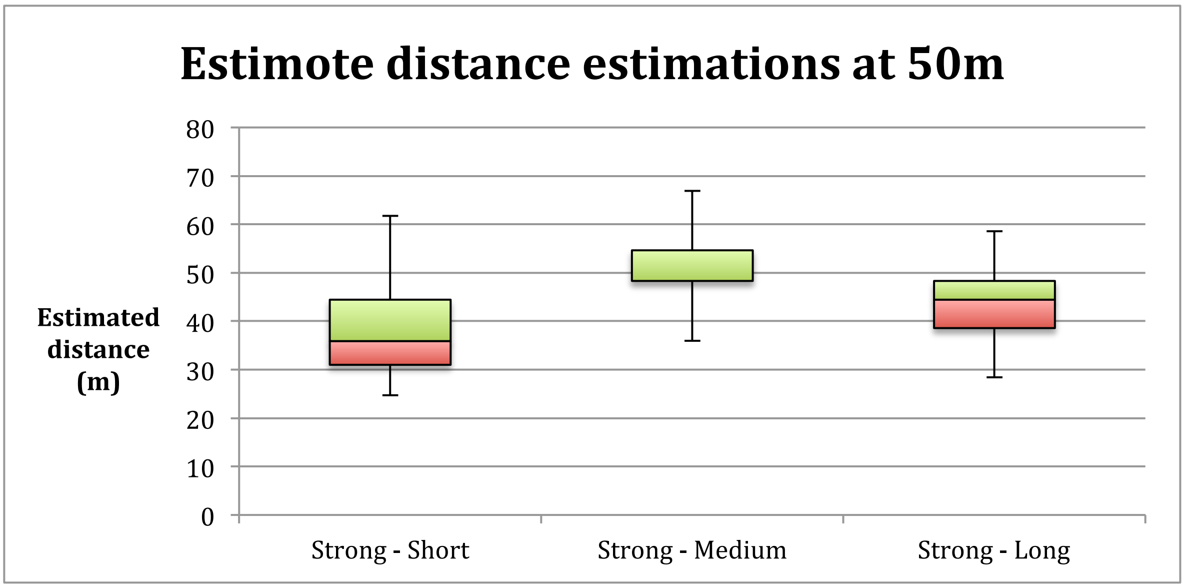

Figure 14: 50m accuracy-testing results

4.2 Orientation & position

According to Estimote, their beacons propagate a Bluetooth signal in all directions simultaneously, forming a sphere. (Puchta 2015) The following section will investigate this claim, determining if the received RSSI value is unaffected by beacon orientation or device position.

Two tests were performed, the first a direct line of site, RSSI measurement with beacon orientation being the only variable. Secondly, a more real world test measuring the received RSSI value at 3m, with the device located in the right and left trouser pockets and also in hand at chest height (common places for a mobile device to be kept). The beacon will also change location for this test, being placed on the floor, the ceiling and on a wall at chest height. For the left/right pocket tests, the user will be standing side-on to the beacon with their right side facing the beacon.

Note: RSSI is a measure of the power present in a received radio signal. This value is commonly a negative number with smaller values regarded as a stronger RSSI. For the purposes of simplifying visualisation in this investigation the RSSI value has been converted to positive though taking a modulus **a smaller value is still regarded as a stronger RSSI value.**

To ensure a fair comparison across all tests the following variables remained constant:

- The same mobile device was used. (HTC One M9)
- All testing was conducted in the same room with clear line of site
- Application logged all signals received for 30 seconds, performing one scan per second.
- The beacon will have a ping delay of 1000ms and a power output of -12dBm.

The results from the first test (Figure 15) clearly show a disparity between the front and back orientations compared to the top, bottom, left and right orientations. The front and back orientations demonstrate higher signal strength with smaller error bars and more precise average values. This shows the beacons operate most effectively when placed vertically. The difference in vertical to horizontal orientation equates to a 2.5m difference in distance estimations. (See Appendix B)

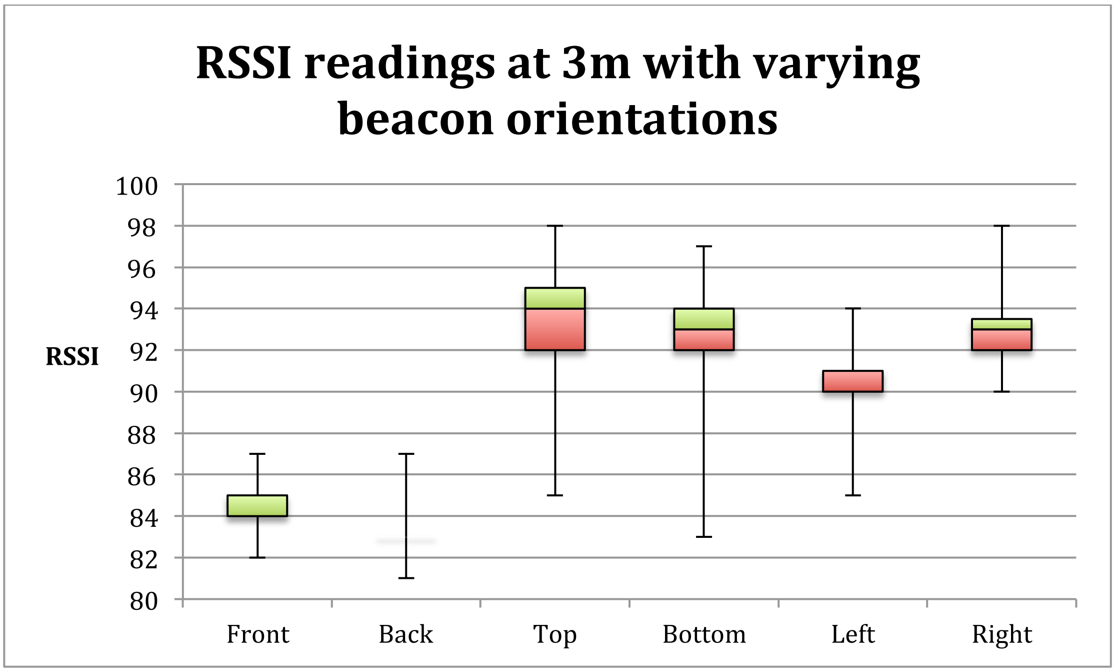

Figure 15: Graph displaying average RSSI measured from different beacon orientations.

This inconsistency should be accounted for when placing beacons. To maximise beacon effectiveness in terms of range and accuracy, a beacon should be placed perpendicular to the floor on a wall or other similar object. If the situation arises where a densely populated room requires a beacon region; a festival marquee for example, then a beacon placed in the centre of the room, on the ceiling with the front facing down would prove most effective.

The results (See Figure 16) for the second test indicate a significant RSSI drop when the device is placed in a pocket, particularly the pocket furthers from the beacon. (The test subject was stood with their right side facing the beacon, forcing the signal to pass through the body to get to the device in their left pocket.) When the beacon is placed at chest height, curiously the RSSI difference is negligible for both pockets, however still considerably less than when the device is held in hand. The test indicates that a beacon placed below the device will result in the strongest signal. Though this may not hold true for a crowded environment. Beacons placed at height would negate some of the signal dampening effects from crowded environments (See Section 4.3) and may result in a stronger overall beacon signal.

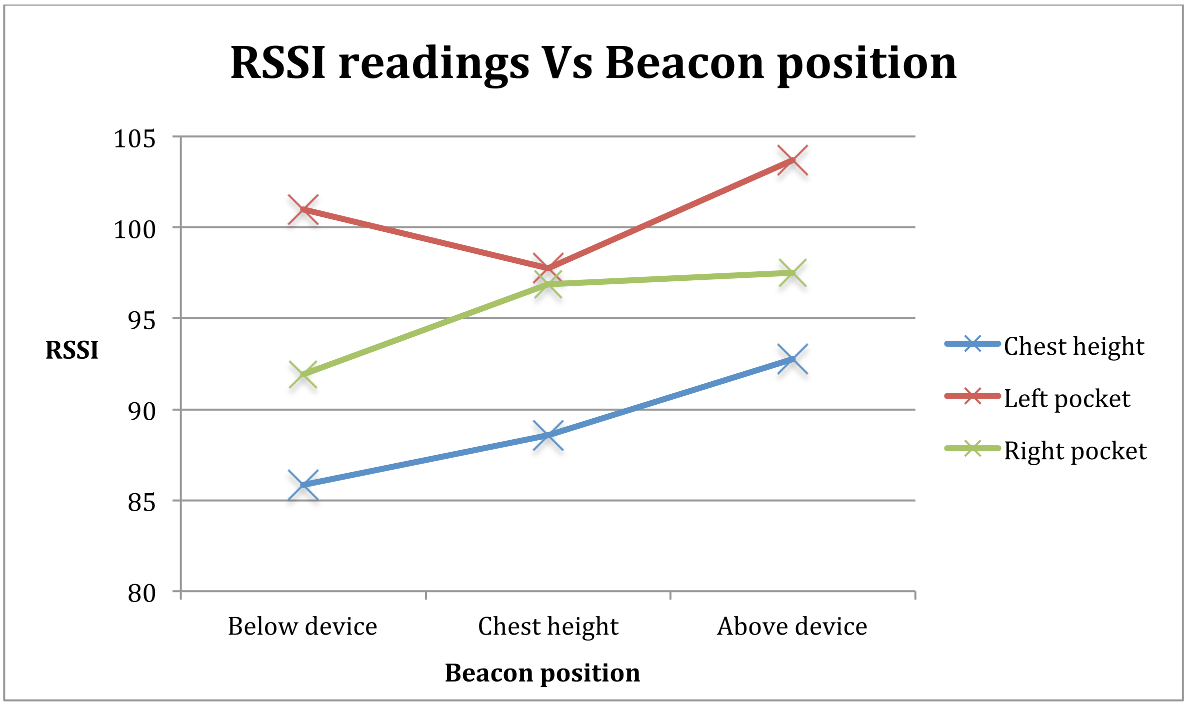

Figure 16: Graph displaying average RSSI measurements from real world situations.

4.3 Signal Strength

The following section will investigate the effect obstructions have on the RSSI value received by a device. Given a festival environment, a BLE signal may have to pass through hundreds of people, competing wavelengths and other obstacles before being received at the intended destination. This must be taken into consideration when determining if beacons are a suitable technology for a festival environment.

To ensure a fair comparison across the proceeding tests the following variables remained constant:

- The same mobile device was used. (HTC One M9)
- All testing was conducted in the same room
- Application logged all signals received for 30 seconds, performing one scan per second.
- The beacons will all have a ping delay of 1000ms and a power output of -12dBm.
- The beacon will be placed 20cm behind the obstruction

Festivals can draw crowds of up to 100,000 people, a serious concern when attempting to emit radio waves at up to 70m. The following test will assess how much 0,1, 2 and 3 human bodies affect a radio wave by placing a beacon at chest height behind the obstruction. 2.8m away on the opposite side of the obstruction a mobile device will be receiving all BLE signals that pass through. (See Figure 17 for diagram) The average received RSSI for the test can be found in Figure 18. The Standard deviation for this test can found in Figure 19.

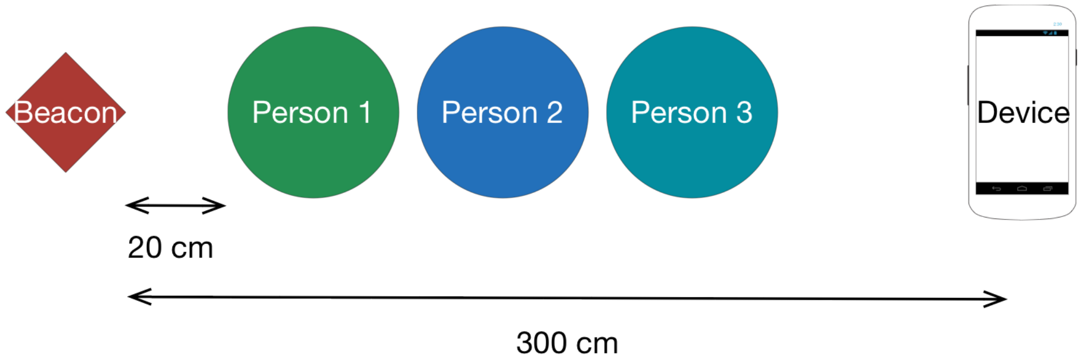

Figure 17: Human obstruction test diagram. (Not to scale)

As expected there is an obvious relation between the number of human obstructions and the RSSI value. The RSSI suffers by only 1.7 with a single obstruction; however, when more are added the RSSI drops considerably. With such a small data set it is difficult to estimate the level of interference a crowd of people would create. That said it is clear that the human body is a substantial dampener for radio waves. For a festival environment it would be wise to amplify the power of the beacons by 25% to accommodate for large crowds.

The standard deviation for this test was interesting; with no obstructions the deviation rested at approximately 1. This is to be expected when using radio waves, due to background interference. What was curious is the deviation plateau that occurred with any number of human obstructions. By introducing any obstruction the deviation trebles; this would be a concern when dealing with precise measurement. This data rules out the ability for precise measurements within crowded environments.

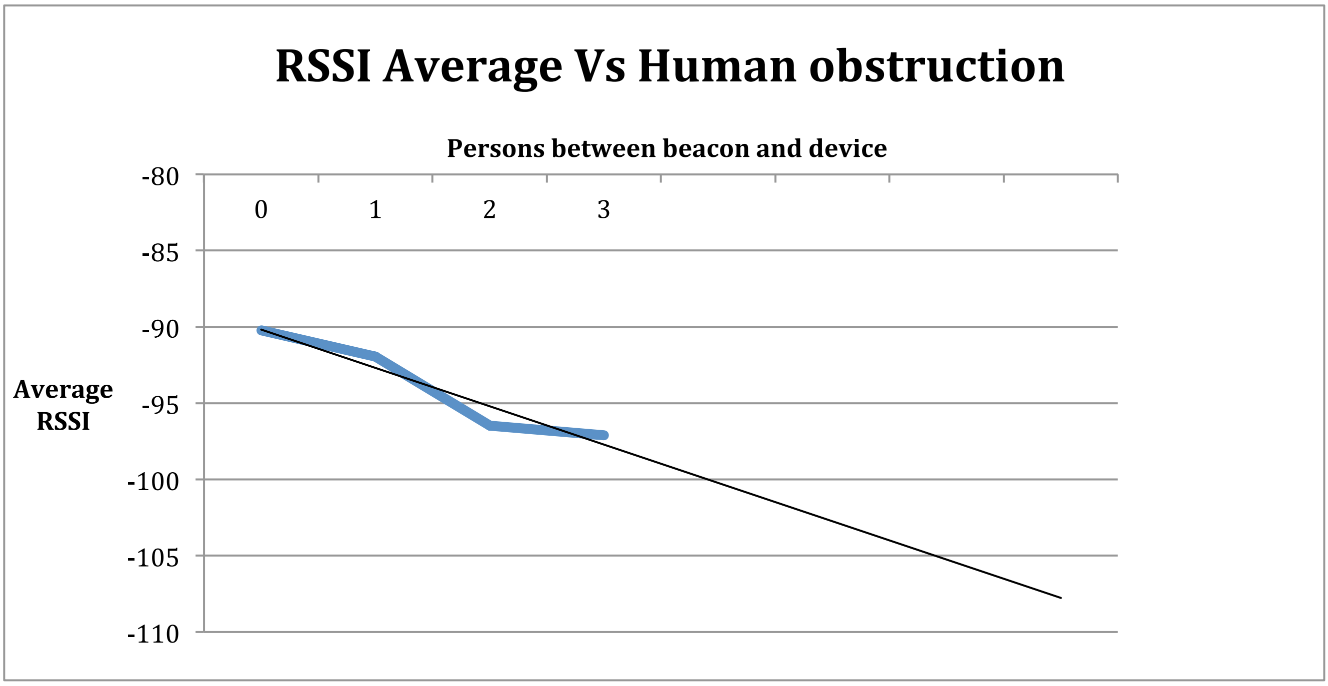

Figure 18: Average RSSI readings at 3m with 0-3 human obstructions.

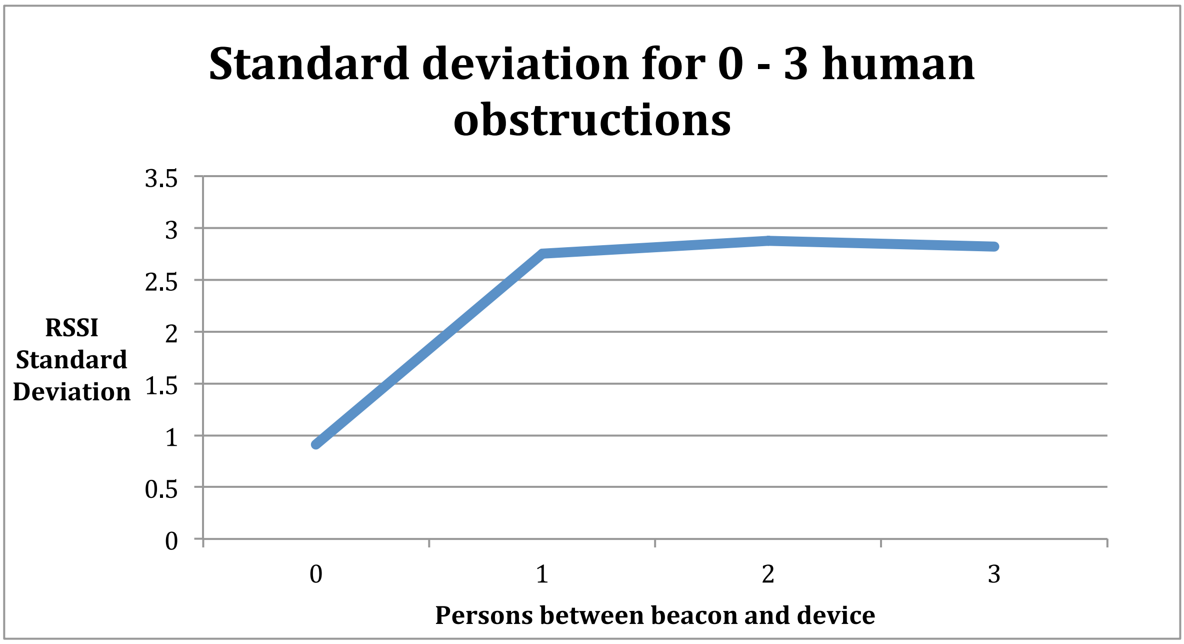

Figure 19: Standard deviation at 3m with 0-3 human obstructions

The following test assesses how competing radio waves affect the RSSI from a beacon to mobile device. For this test, two laptops were placed on a desk 40cm apart, both devices continuously streaming a large video file throughout the test, over Wi-Fi. (WiFi operates on a 2.4GHz radio wave, the same as BLE) The beacon was placed behind these devices, with the beacon-scanning device placed 3m in front. (See Figure 20 for diagram). With this design, the BLE signal emitted from the beacon must pass through a high density of waves being sent from a home router to the laptops. This level of interference is extreme compared to the interference expected at a festival; the results from this test are a worst-case scenario for interfering radio waves.

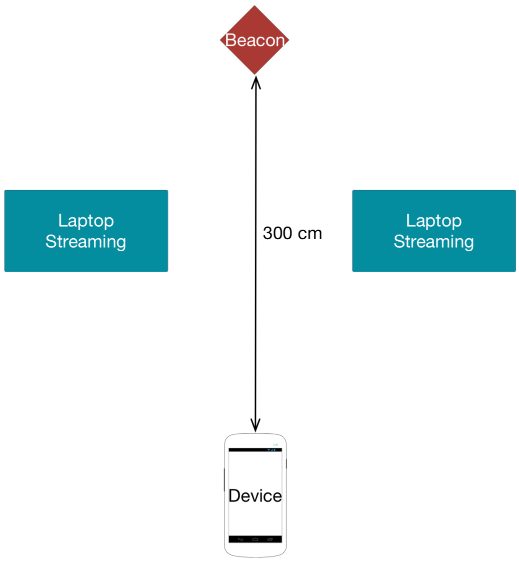

Figure 20: Signal interference diagram

Table 1: Signal interference and no interference results

	Max (RSSI)	Min (RSSI)	Average (RSSI)	Standard Dev (RSSI)
No interference	-92	-88	-90.23076923	0.908083358
Substantial interference	-103	-93	-97.57692308	2.872950775

The results from this test are presented against a previous test with no obstructions in Table 1. These figures demonstrate a significant decline in RSSI when the emitted radio waves are subject to interference. There is also a considerable standard deviation increase, which would be a concern when precise measurements are a requirement. The substantial interference results are similar to that of a previous test where three people blocked the beacon signal. It must be noted that this level of interference is extreme; the close proximity of two devices streaming a large file will certainly propagate high densities of radio waves. This density of interference would be abnormal for a festival environment, though should be considered when placing beacons in areas with a high density of electronic transmissions. Signal interference could be avoided almost entirely if the festival used temporary cellular data masts. These masts could be configured to operate at a different wavelength – reducing the interference between the beacons and the mobile network.

4.4 Scalability

Up to now this investigation has only experienced beacons on a small scale. One device to one beacon for testing purposes, twelve devices to six beacons for the UCAS open day. Unfortunately, this investigation does not have the resources to test beacons to their full potential at scales required by a festival, though discussion can be had into the possible difficulties a beacon-enabled application may experience operating at a larger scale.

Firstly, it is a common misconception that beacons receive information from nearby devices; beacons only emit a unique identifier. For this reason, the number of devices receiving a beacon's signal has no limit and no negative impacts on the beacon hardware. A beacon will operate consistently with a single device, as it does with a thousand.

With regards to the local processing of multiple beacons simultaneously, this should not cause issue either. Throughout this investigation a simple testing application has received and processed nine beacons simultaneously on a single thread with no evident struggle. If the situation arises where an application needs to monitor multiple beacon regions, performing resource intensive processes for each, then threading can be implemented with optimisation improvements if required.

The only foreseeable problem with developing a large-scale beacon application is the central server bandwidth and processing capabilities. For instance, if 50,000 festival attendees were all using the application simultaneously, all entering and exiting beacon regions, this would create an incredible amount of data for the server to handle and process. To manage this level of data, investment would be required for significant hardware capabilities, along with a particularly fast Internet connection.

Section 5: Demonstration: UCAS open day Tour Guide

To gain a comprehensive understanding surrounding the design, implementation, deployment and effectiveness of a beacon-powered application, it seemed appropriate to fully implement, deploy and demonstrate a beacon-powered application. Through discussion with Stuart Allen[7], it was determined that a suitable opportunity for demonstrating this application would be in partnership with the UCAS[8] Computer Science open days at Cardiff University on the 7th and 11th of March 2015. During these days, parents and students will visit the University and tour the Computer Science and Informatics building. The UCAS day consists of several talks and discussions surrounding the university and the school's available courses, a tour of the school, a tour of Cardiff Universities' Student's Union, one to one discussions, lunch and a Python lab session. The full itinerary can be found in Appendix C. This application was designed to offer additional information to open day attendees relevant to their current location, while providing feedback to a server in the form of log files detailing user interaction with the app and with the beacons. The following sections discuss the development process, findings and complications with this mobile application.

5.1 Objectives

This mobile application was designed primarily to support the investigation with practical, primary research regarding the creation of mobile applications with Estimote's beacons and SDK. Secondly, this application was designed to offer a service to the attending parents and students on the UCAS day. Below is a list of objectives this application intended to achieve.

1. Develop a professional Android application utilising Estimote's SDK to interact with Estimote beacons.
2. Deliver beneficial, location specific content to users accurately when entering beacon regions.
3. Incorporate a questionnaire into the application for user feedback
4. Deliver notifications to users when entering a beacon region.
5. Acquire beacon interaction data for analysis of a real-world application.
6. Develop a reliable client-server system for sending data from local devices to a central server for data analysis.
7. Upload the application to the Google Play store and perform a full demonstration on the UCAS open days.

[7] Project Supervisor, Reader/Director of Learning & Teaching/Deputy Head of School
[8] Universities and Colleges Admissions Service

5.2 Development

The initial concept for a virtual tour guide went as follows: A beacon would be placed in every room visited by the tour. When the attendees entered the room, the mobile application would recognise the beacon and trigger location specific content to be presented on the UI and a notification pushed to the Android notification drawer. Simultaneously a log file would be updated with data such as the current time of beacon recognition, the distance from device to the beacon and details regarding user interaction with the notification. Once updated, the log file will be sent to the server where the data received will be used to update a central log file. Upon entering the final location of the tour, a questionnaire will display instead of information. The user has the option to fill in the questionnaire and submit it; at which point the questionnaire answers will be stored in the local log file before being sent to the server.

When designing the application it was essential to reduce development time as much as possible due to only having four weeks available for development. With this in mind, a simple user interface with four screens was designed. As seen in Figure 21, the interface consists of four tabs. The BEACON tab displays beacon dependant information relative to the closest beacon. The second tab, HISTORY, displays a list of previously visited beacon locations. The last two tabs, CARDIFF and COMSCI contain information and images regarding the city of Cardiff and the school of Computer Science and Informatics respectively.

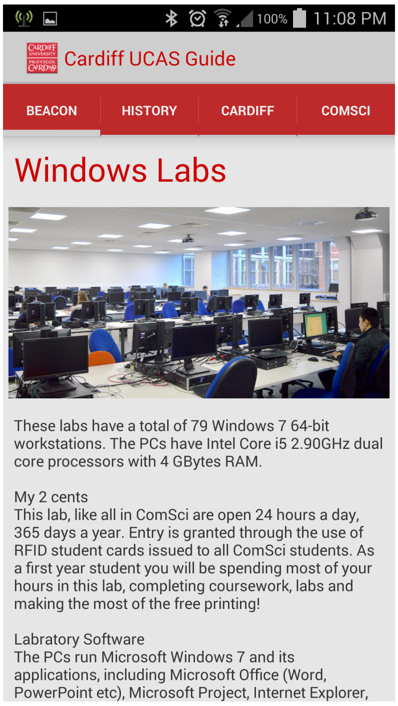

Figure 21: Cardiff UCAS Guide interface

When designing the beacon interaction aspect of the application, it was important to minimise the complexity. A minimalist approach reduced development time, ensured a more robust system and enabled a simpler UI, while sacrificing some functionality. Considering this, the only user perceived functionality was to provide one page of content specific to the recognised beacon. This page consisted of a title, image and text.

Beacons only provide a unique identifier; this identifier can be used as a trigger to search for the relevant content and display on the UI. This could be done in one of two ways; firstly the application could request content from a server providing the beacon identification as a parameter. Secondly, the content could be stored and retrieved locally. The first approach would require a database of content stored on the server, the server would be required to manage requests and deliver serialised objects.[9] The second approach would require content to be stored locally and uploaded with the application to the Google Play store. It would also require a class for converting a given beacon identifier into presentable content.

- [9] Object serialization - Converting objects into a format that can be transferred over a network, often as a byte stream.

Based on the requirements for each approach and aiming to minimise complexity, the second approach proved best suited. However, when developing a beacon application for a more permanent, maintainable system it would be necessary to host the content external to the application. This would allow for content to be changed without updating entire applications. When dealing with substantial amounts of content it would also minimise application size. For this application, content was minimal and would not need to be updated favouring the content to be stored locally.

In terms of local Android storage there were several options. An SQL database would provide the most structure and functionality for the data; that said, it would require a lot of design and error testing. This application only required six pages of content deeming a database to be unnecessary. Secondly, Android offers a SharedPreferences class for storing permanent small amounts of data within the Android file system. Its intended use is for application specific user preferences. This would have been suitable, however the data being written to SharedPreferences would have to come from somewhere within the application. It was logical to avoid SharedPreferences and simply store the content as objects in the JVM Heap[10]. For this method, a Content class was required for storing the various components of information (See Figure 22). A class is also required to manage the conversion from beacon identifier to content (See Figure 23). ConvertBeaconToContent.java manages this, providing two constructors for beacon identification. The first takes a Beacon object parameter, the second an Integer – the integer being the Minor value of a given beacon. This value is than processed in a Switch statement to determine the appropriate Content object to create and return

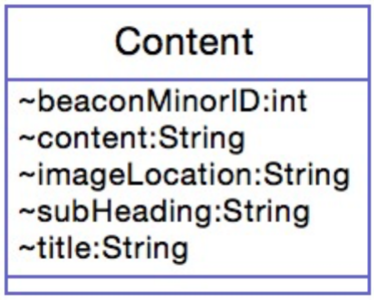

Figure 22: Content.java

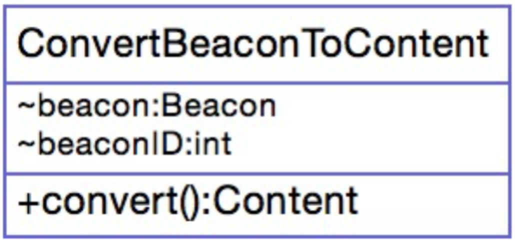

Figure 23: ConvertBeaconToContent.java

The Estimote SDK offers two methods for interacting with their beacons, Ranging and Monitoring. "Ranging gives you the exact list of beacons detected in a given region, together with an estimated distance from the device to each beacon." "Monitoring a region enables your app to know when the device enters and exits the range of beacons defined by the region." (Borowicz 2015) Monitoring can be used whether the application is open or in the background, where as Ranging requires the application to be open. For a virtual tour guide, the Monitoring method was more suitable as precise measurements were not required, only determining which beacon region the user had entered / exited. It was also a necessity for the application to continue monitoring when the application was not open, for example when a user's device was in their pocket. For Monitoring to begin, a BeaconManager object must be created to manage the incoming beacon signals. BeaconManager is the core class for managing all beacon interaction requirements including functionality for creating beacon scanners, configuring scan periods, setting beacon listeners and checking if Bluetooth is enabled on the device.

[10] A Heap is the Java runtime data location where all class instances are stored.

A threaded class – BeaconScanner.java was designed to run independent of the main Android UI thread to ensure that users could still interact with the application while scanning for beacons. A callback interface was designed – BeaconCallback enabling the threaded BeaconScanner class to relay data back to the main BeaconFragment class in order to update the UI. BeaconScanner was responsible for continuously scanning for beacons and managing the triggers when a beacon region was entered. Beacon scanner coordinated the BeaconManager, pushed data to the UI, updated the log file and was responsible for updating the server when a new beacon was discovered.

A requirement of this application was to provide beacon interaction availability when the application is closed. To facilitate this, functionality had to be designed to delivery notifications to the user upon entering a beacon region. This could be accommodated with Android's Notification class. Using a Notification Builder it is possible to construct and post a notification to the devices notification drawer.

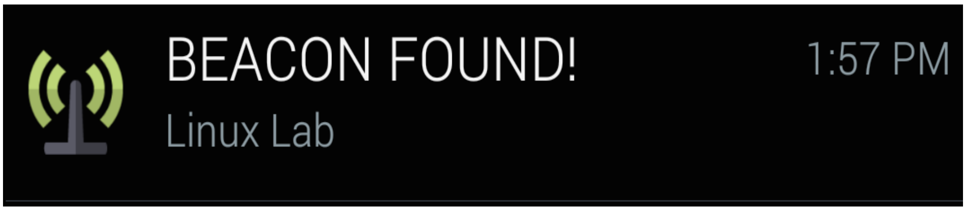

Figure 24: Beacon notification Linux Lab example

The Notification class can handle the format, content and interaction with the notification. The notification design consisted of a PNG beacon icon, a title and subtitle. The title and beacon icon were consistent no matter which beacon region was entered. The subtitle specified which region had been entered (See Figure 24). BeaconScanner provided this information when the device entered a beacon region.

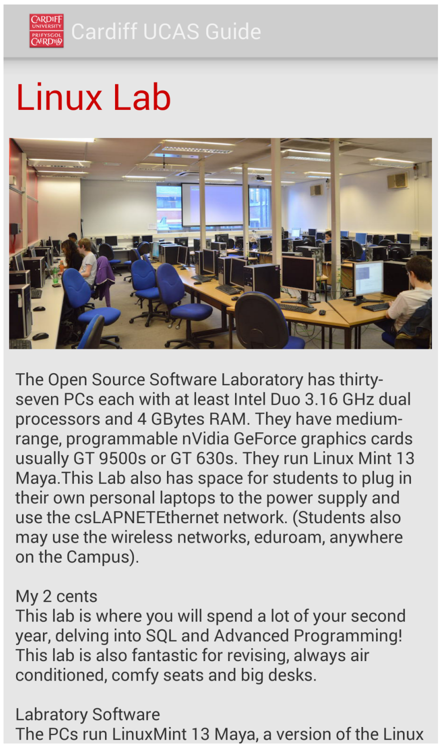

Figure 25: Linux Lab content

Upon the user selecting a notification a new interface is initialised displaying the relevant content for a given beacon region (See Figure 25 for Linux lab example). This interface is separate from the core application allowing the user to efficiently browse only the content they selected from the notification drawer. The layout used for this interface is consistent throughout the application providing a uniform experience.

It was only necessary to create a notification the first time a user entered a region. Being notified every time a device passes into a beacon region would become an annoyance while providing no extra information. To track which beacons had been visited previously required a BeaconTracker class. This class would be responsible for monitoring which beacons had been previously recognised; ensuring duplicate notifications were not created. Beacon tracker was also used to populate the History tab of the user interface.

An objective of this application was to track user engagement with the app and acquire beacon interaction data. This objective could be facilitated through the use of a local log file. The log file was created on the applications initial run and the associate devices details are appended to the file. The log file was then updated every time a user came in contact with a beacon, opens a notification, or interacts with the app. The file was stored on the devices local application specific memory and pushed to the server every time a new beacon was recognised. An example log file can be seen in Figure 26.

```
357336065746387.csv
#USER: buildteam
#BUILD VERSION: 5.0.1
#DEVICE: htc_m8
#MODEL: HTC One_M8
#PRODUCT: vodafone_uk
#HARDWARE: qcom

# MAIN ACTIVITY RESUMED

# MAIN ACTIVITY PAUSED

# MAIN ACTIVITY RESUMED

D 7 0.989954740160185

B 7 10:58:32

# MAIN ACTIVITY PAUSED

D 1 8.55272698336918

B 1 11:10:39

D 3 1.234273624425309

B 3 13:56:39

D 2 3.437479461605996

B 5 11:22:28

D 4 14.29475636464428

B 4 14:04:15

D 5 4.398583742102257

B 5 14:44:28
```

Figure 26: Example log file

A Client.java class was designed to manage the client – server communications. Client.java extends AsyncTask – an Andoid abstract class enabling a process to be completed in the background of the application. Client.java is responsible for updating the server with the most current log file. This can be broken down into five steps.

1. Ensure a stable network connection.
2. Connect to the server.
3. Send the unique device ID for use as a file name on the server side.
4. Send the log file as a byte stream.
5. Close the connection and return.

See Appendix D for the full Android application class diagram, and Appendix E for the interaction diagram.

A Java server was designed to handle the log file reception. The server consisted of two classes: Server.java and ServerThread.java. Server.java was responsible for opening a Socket and listening for incoming connections. When an incoming connection was established Server.java initialised a new ServerThread object to manage the connection while Server.java remained listening for new connections.

ServerThread.java extended Thread enabling multiple connections to be managed simultaneously. ServerThread.java was responsible for receiving the incoming byte stream before compiling the log file and storing it locally. This can be broken down into four steps:

1. Gather the input stream from the open socket
2. Store the device ID from input stream
3. Convert remaining stream to a byte array
4. Parse byte array to a new file using the deviceID as a file name.

The external Java library, Apache Commons was utilised during step 4[11]. The library offers a useful file IO class called FileUtils. This class has a method called `writeByteArrayToFile` that achieves step four in one command. Apache Commons was utilised to offer a secure, simple way of converting the byte array to a file.

5.3 Outcome

This application resulted in a successfully implemented and positively received beacon-enabled virtual tour guide. The tour guide was uploaded to the Google Play store[12] as originally intended; the UCAS day attendees were provided details of the application prior to the day via email.[13] There were approximately 50 attendees on the 7th March with the app being utilised by 12. Unfortunately, due to network issues the application was not functional for the second UCAS day on the 11th March (Discussed in Section 5.4).

The 12 attendants that successfully used the app on the 7th provided excellent data regarding the effectiveness of beacons for a virtual tour guide. There exists a clear pattern throughout the log files that mimics the intended tour routes. Appendix F contains a compiled table of all beacon recognition times from all users, complete with notification open and close times. Appendix H contains a table of beacon configurations for the UCAS open day. There exist some discrepancies regarding beacon recognition according to the log files; for instance some users recognised beacon 1 (The Windows Lab) much earlier than anticipated. This may be because some devices picked up the beacons signal from outside the room while walking past. Beacon signals were not intended to surpass the confines of the given room, this was tested prior to the UCAS day; however, only with one device[14]. For future beacon deployments it would be wise to test a beacons range with multiple devices to ensure beacons aren't recognised outside of their projected range. A second discrepancy involves some users not recognising a beacon at all; this may have been because there were too many obstructions between their device and the beacon or some users chose not to enter a beacon room and so stood out of range.

The questionnaire was delivered to the attendees upon their entry to C/2.07 – the final room of the tour. Users were asked to provide a rating (from 0 to 4) relating to how much they agreed with the following 10 statements:

1. The response speed when entering a beacon zone was fast
2. The application was successful as a secondary tour guide
3. I would like to try more contextually aware applications
4. I am concerned with the privacy aspects surrounding beacon technology
5. I found the contextually aware information beneficial
6. Notifications were triggered accurately upon entering a beacon designated environment
7. I am interested to find out more regarding beacon technology
8. I would be more likely to download and install a beacon enabled application

[11] https://commons.apache.org/
[12] https://play.google.com/store/apps/details?id=com.adamprobert.cardiffucasguide
[13] I was present on the day to introduce the application personally to the attendees and also to answer any questions regarding my dissertation or the application.
[14] The device used for testing was a Samsung Galaxy S4.

9. I noticed the application affected my devices battery
10. Overall I am impressed with the functionality of this application

Six of the 12 users answered the questionnaire (See Appendix I). These results have been accumulated into averages and presented in the following format (See Figure 27). For exact results see Appendix J.

Through interpretation of this data it can be established that the response time and accuracy for the applications' beacon recognition was precise, scoring averages of 4 and 3 respectively. This shows that the beacon configuration provided effective regions and that the application recognised and processed the given beacon signals efficiently. For this application, beacon placement consisted of placing the beacon in the centre of the room and increasing the signal power to the point where it reached the perimeters of the room. Tests were done to check the signal did not surpass the room.

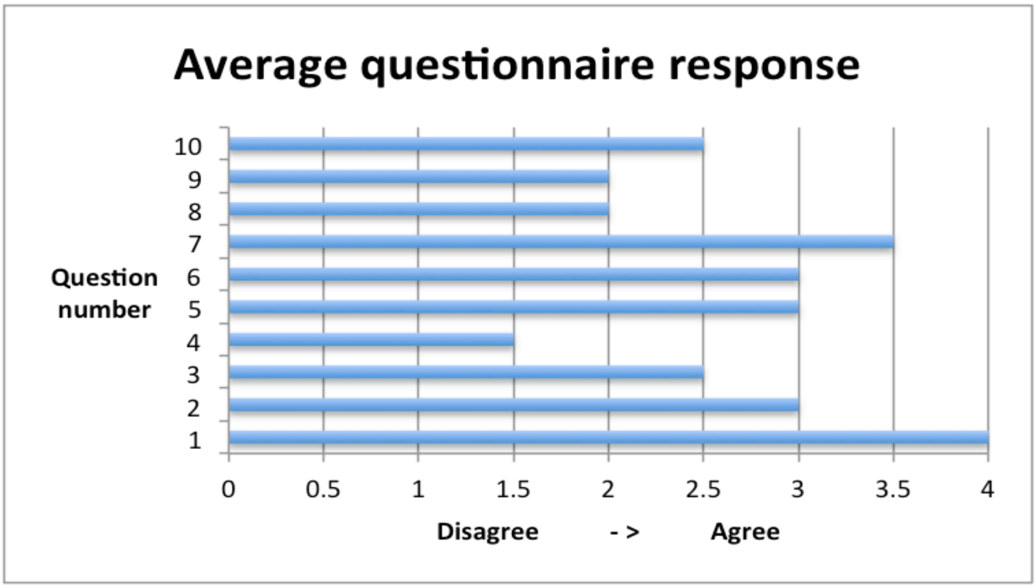

Figure 27: Average questionnaire responses

It can also be established that the application was an overall success. Users scored performance of the tour guide at a 3, also scoring the information as beneficial with a score of 3. However users were not overly impressed with the functionality of the application, scoring an average of only 2.5 with the lowest response being 0. This may be because there was only one apparent function being the beacon recognition. Provided a longer development time more remarkable functionality utilising the beacons could be developed.

Question 4 establishes how concerned users are with the privacy aspects of beacon-enabled applications. It returned the lowest average score of 1.5 with all scores ranging from 1 to 3. This shows that either users do not have privacy concerns, or they do not understand what privacy concerns there may be surrounding this technology. Question seven response supports the latter scoring a 3.5 for users interested in finding out more about beacon technology.

Device power consumption went relatively unnoticed throughout the day with users being impartial to experiencing battery loss. These users had their mobile phones on with the tour guide permanently scanning for approximately six hours during the day. For battery consumption to go relatively unnoticed validates the BLE name (Bluetooth Low Energy) and enables beacons to be a viable technology for when battery consumption is of primary concern such as at a festival.

5.4 Complications

While developing this application some unexpected complications occurred. Firstly limited mobile - Internet connectivity had not been considered. Hence the first mobile - server connection failed and crashed the application. Allowances had to be made for poor or no connectivity from the mobile device. This was done with the following code found in the Client.java class.

```
ConnectivityManager cm = (ConnectivityManager)
context.getSystemService(Context.CONNECTIVITY_SERVICE);

            NetworkInfo activeNetwork = cm.getActiveNetworkInfo();
            boolean networkConnected = activeNetwork != null &&
activeNetwork.isConnectedOrConnecting();

            // Waits for a secure connection
            while (!networkConnected) {

                  activeNetwork = cm.getActiveNetworkInfo();
                  networkConnected = activeNetwork != null &&
activeNetwork.isConnectedOrConnecting();

                  try {
                        Thread.sleep(5000);
                        Log.d("UCAS", "CLient - waiting for secure connection");
                  } catch (InterruptedException e) {
                        Log.e("UCAS", "Client - Error waiting for internet connection");
                        e.printStackTrace();
                  }

            }
```

An Android ConnectivityManager object is instantiated with the network system service. Then the network information is collected and stored in a NetworkInfo object, this object is used to check the state of the network. A while loops is then used to wait for a network connection. It is set for five-second iterations. Once an Internet connection has been established the code continues to request a connection with the server's open socket.

This method for checking an Internet connection was suitable for this controlled application; however, further checks should have been done to ensure a secure connection to the server. Because this had not been implemented the second UCAS open day could not go ahead. The public IP for the server had inadvertently changed resulting in crashes from mobile devices with an Internet connection but unable to connect to the server. Had further checks been implemented for complete client – server communication, this could have been avoided. A second problem with this method is the lack of a time-out function. This will result in multiple threads waiting for a connection that may never come; this leads to wasted resources and possible memory leaks.

A second complication arose when trying to uniquely name files on the server. The server needed to maintain a directory of log files uniquely named to clients. At first this seemed to be simple; the server could name the files incrementally as they were received. Though this caused problems when needing to overwrite the files as the server did not record which files corresponded with which client. This was resolved from the client side by accessing the devices IMEI[15] number. This number could then be sent to the server previous to the log file and be used as the file name on the server. One issue with this implementation is the lack of an IMEI code for tablets. Had someone wanted to use this application with a tablet the application would not have found a unique name for the log file and the application would have crashed.

5.5 Review & Conclusion

This application proved to be a success with the UCAS day attendees; they found the information provided to be beneficial and delivered accurately upon entering a beacon region. It was apparent that there was a lack of understanding as to how the beacon technology worked and there was certainly a notion to learn more about it. This demonstrates a willingness from the public to try new location-based technologies if available.

Developing this application demonstrated how simple Estimote have made location-based application development. Their attractive and intriguing beacon hardware complete with a robust, developer-friendly SDK will lead the way for app developers contributing to the IOT. The only issue with Estimote as a beacon provider is their lack of support for the Android SDK. Since the initial SDK in December 2013, there have only been a handful of bug fixes and optimisations with no new functionality. On the contrary, the iOS SDK receives new functionality and bug fixes weekly. Hopefully this level of commitment will become evident for Android users in the near future.

When deploying the beacons, it was clear that precise beacon zoning would be impractical given an outdoor environment. For this application beacon regions were confined to individual rooms with physical walls and doors to block the signal surpassing the boundaries of the room. The physical boundaries worked very effectively at containing the signal within the room. With no physical boundaries, limiting the beacon signal to a very precise area will prove difficult.

From a personal standpoint developing this application has enhanced my programming ability substantially; utilising external hardware and experimenting with a new technology has been very rewarding and I have acquired a lot of experience managing an Android application. If there had been more time available to develop this application further, I would have liked to experiment with more advanced client – server communications and

[15] IMEI – a unique 15 digit code used to identify mobile phones

achieved a stronger system to manage poor connectivity. Server – client communication was very interesting as my only experience (previous to this application) was theoretical. It was rewarding to apply theoretical knowledge acquired from my course to a professional application without the constraints of a standard coursework piece.

Section 6: Future Work

The future for beacon technology is likely to progress into numerous areas of society. Beacons are already being used in retail outlets, museums, galleries and airports. Due to their simplistic design beacons can be deployed in limitless situations providing contextual data for multitudes of applications; an attractive characteristic for a developer. Beacons are likely to become commonplace in society, optimistically with a single company providing the hardware and an interface for developers to work with to create a truly integrated, connected world. If not a single company, then an industry standard agreed upon to encourage connectivity throughout the beacon industry.

In terms of festivals, beacons should make quite an impact over the coming years. Their capabilities can be used for a variety of possible applications (See Section 3), aimed at improving the experience, bringing organisation to chaos, offering clever ways of marketing and gathering crucial data for festival organisers. Beacons could be designed specifically for festivals with a stronger outer-shell and increased power output for increased range. A beacon would only require power for the duration of the festival; hence beacons could utilise both BLE for their current use and also Bluetooth 2.0 for transferring data to and from devices removing the requirement for the users device to have Internet connectivity.

Regarding Estimote, their development of the iOS SDK is likely to continue into the areas of indoor mapping and live device tracking. Hopefully they will resume development of the Android SDK, as there is great appeal for this from both the Android and beacon community. Their work thus far has made them industry leaders, if they continue with the commitment they have shown this past year they are likely to dominate the beacon industry. I believe this would be good for developers and consumers alike, as it would endorse universal applications for managing multiple venues and companies; for example, a single application for all museums in the UK, configurable by the individual museums but a single standard application for consumer simplicity.

Beacon hardware may become a thing of the past, there are frustrating setbacks to the current implementation; for instance setting individual beacon zones is a tiresome undertaking when managing large quantities. Replacing batteries is another setback. Estimote state their batteries last for up to five years; this may be the case if the beacon is set to minimum power output and the longest ping intervals, though this is impractical for most applications. It is estimated the beacons should last approximately six months with standard use. Replacing a stores worth of batteries every six months is both costly and time consuming. In the future virtual beacons may replace the physical beacons we have today, through improved mobile phone sensors and space-mapping software.

Personally, this investigation has provided me with insight into this exciting new technology; I have become a supporter of their fantastically simple functionality that is easy to utilise and build upon to create ingenious applications. I have been contacted by an Engineering lecturer at Cardiff University with plans to develop a beacon-enabled application for the Doctor Who Experience in Cardiff. Requirements similar to the UCAS Tour Guide (See Section 5) have been specified and I am currently in the process of securing this project for the coming summer. This is a very exciting opportunity and I am looking forward to the end-to-end development of a commercial application, which could enhance the Doctor Who Experience for hundreds of customers every day.

Section 7: Conclusion

This investigation aimed to determine if beacons are a viable technology for festival environments; intending to assess the capabilities and limitations of beacon hardware, explore beacon SDK development, review current beacon-enabled applications and propose possible festival related applications powered by beacons.

Estimote's beacons work well for their intended functionality, this being to signal devices in close proximity of their location. This was demonstrated with the UCAS tour guide, where the beacons worked very effectively with minimal time allocated to deploy and test their ranges. Participant feedback corresponded well with the statistical data regarding accuracy of beacon notifications, further demonstrating the beacons effectiveness to work as intended. Applying this knowledge to a festival context, beacons should work as effectively for applications such as advertising merchant promotions and calculating crowd densities. Estimote beacons do not offer sufficient accuracy for precise location positioning; the use of RSSI to determine distance may offer a rough estimate but cannot be relied upon due to the level of deviation found with and without obstructions.

Estimote's SDK proved very simple to work with. Offering two methods for beacon interpretation, ranging and monitoring; these methods were very useful for different situations. Monitoring allowed for registering when a device entered and exited a beacon region, managing a lot of the low level interpretation leaving the developer free to build functionality triggered by this method. Ranging provided the raw data for recognised beacons; this was very effective for testing and deploying the beacons on the UCAS day. Now that Estimote have developed the core beacon interaction software, hopefully they will move on to develop some more advanced functionality such as room mapping and live user tracking.

Beacon technology is spreading throughout society, more and more retailers are adopting this new method for consumer interaction and it is proving to be very effective. Museums, galleries and other such attractions are quickly becoming 'beaconized', offering interactive ways for visitors to interact with their exhibits. Airports are developing new method for aiding passengers throughout their airport experiences. With the insight from this investigation we may see beacons integrated into festivals throughout the country, optimistically beacons may even become fundamental for a festival experience.

To conclude, I would consider beacons as a viable technology for a festival environment if used as a proximity notifier. They work evidently well in real-world applications that require an approximate location. In their current state, beacons should not be relied upon for determining precise location. I believe beacons could radically enhance the festival experience for festivalgoers by providing contextually based information and assistance conveniently to individuals. This technology would remarkably aid festival organisers and staff when designing and managing festivals to better accommodate crowds, attractions and entertainment to provide an all-round improved experience for everyone involved.

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Appendix

Appendix A: Processed accuracy measurements

Distance: 0.5m

Power	Ping delay	Min(M)	Q1	Median	Q3	Max
	short(100ms)	0.66785971	0.84806437	0.84806437	0.96666667	2.04512639
Weak (-20dBm 3.5m)	medium(500ms)	2.04512639	2.38585798	2.5381085	3.02817865	3.90505024
	long(1000ms)	1.39839321	2.13936693	3.15766248	3.53900484	3.90505024
	short(100ms)	0.36351308	0.5074363	0.55133696	0.63959123	0.77090006
Normal (-12dBm 15m)	medium(500ms)	0.41856989	0.63959123	0.63959123	0.77090006	0.87885104
	long(1000ms)	0.63959123	0.98666667	1.09354947	1.09354947	1.29886421
	short(100ms)	0.58736445	0.86248941	0.86248941	0.96	1.08757354
Strong (4dBm 70m)	medium(500ms)	0.69394251	0.9112447	0.96	0.96	1.27841213
	long(1000ms)	1.08757354	1.27841213	1.42313236	1.66041944	2.16562118

Distance: 1m

Power	Ping delay	Min(M)	Q1	Median	Q3	Max
	short(100ms)	1.1066185	1.27674227	1.27674227	1.39839321	2.23360747
Weak (-20dBm 3.5m)	medium(500ms)	0.84806437	0.96666667	1.1066185	1.23680817	1.39839321
	long(1000ms)	1.39839321	1.63074598	2.0022637	2.0022637	2.23360747
	short(100ms)	1.62443446	1.98096803	2.29819663	2.70411809	9.67050045
Normal (-12dBm 15m)	medium(500ms)	1.29886421	1.62443446	1.84561401	2.11632205	3.17193628
	long(1000ms)	1.41448147	1.62443446	1.67451206	1.84561401	2.4606027
	short(100ms)	1.5618129	1.97917756	1.97917756	1.97917756	2.16562118
Strong (4dBm 70m)	medium(500ms)	0.96	1.27841213	1.42313236	1.42313236	2.16562118
	long(1000ms)	0.86248941	0.86248941	0.96	0.96	1.5618129

Distance: 3m

Power	Ping delay	Min(M)	Q1	Median	Q3	Max
	short(100ms)	2.73156989	3.43747946	3.64053022	3.77279023	4.48406655
Weak (-20dBm 3.5m)	medium(500ms)	3.64053022	3.90505024	4.41691713	4.41691713	5.49670372
	long(1000ms)	3.43747946	3.64053022	3.90505024	4.28895041	4.48406655
	short(100ms)	2.4606027	2.96943987	3.17193628	3.17193628	4.38352911
Normal (-12dBm 15m)	medium(500ms)	1.84561401	3.91358578	4.00585613	4.38352911	4.38352911
	long(1000ms)	4.38352911	4.98995474	5.37900896	5.71657784	7.73816123
	short(100ms)	2.16562118	2.60003223	2.80104118	2.80104118	3.82294428
Strong (4dBm 70m)	medium(500ms)	2.39902327	2.80104118	2.93397305	2.93397305	5.67053546
	long(1000ms)	2.80104118	4.70445402	5.38318872	5.67053546	6.13569665

Distance: 10m

Power	Ping delay	Min(M)	Q1	Median	Q3	Max
	short(100ms)	0	0	0	0	0
Weak (-20dBm 3.5m)	medium(500ms)	0	0	0	0	0
	long(1000ms)	0	0	0	0	0
	short(100ms)	8.7608617	9.67050045	10.9291621	10.9291621	11.6973442
Normal (-12dBm 15m)	medium(500ms)	7.20646094	8.7608617	8.90188624	9.67050045	10.9291621
	long(1000ms)	10.9291621	10.9291621	10.9291621	13.3708883	13.3708883
	short(100ms)	11.9853887	16.2263524	19.2911871	20.7308795	26.6790626
Strong (4dBm 70m)	medium(500ms)	11.9853887	19.2911871	19.7809683	21.6807907	28.3879436
	long(1000ms)	11.1589216	19.7809683	19.7809683	21.6807907	26.6790626

Distance: 20m

Power	Ping delay	Min(M)	Q1	Median	Q3	Max
	short(100ms)	0	0	0	0	0
Weak (-20dBm 3.5m)	medium(500ms)	0	0	0	0	0
	long(1000ms)	0	0	0	0	0
	short(100ms)	0	0	0	0	0
Normal (-12dBm 15m)	medium(500ms)	0	0	0	0	0
	long(1000ms)	0	0	0	0	0
	short(100ms)	38.5775751	43.7102032	44.4455923	48.3148508	61.7735791
Strong (4dBm 70m)	medium(500ms)	33.8240743	43.7102032	54.6361752	58.508802	61.7735791
	long(1000ms)	38.5775751	44.4455923	54.6361752	55.6043319	61.7735791

Distance: 50m

Power	Ping delay	Min(M)	Q1	Median	Q3	Max
	short(100ms)	0	0	0	0	0
Weak (-20dBm 3.5m)	medium(500ms)	0	0	0	0	0
	long(1000ms)	0	0	0	0	0
	short(100ms)	0	0	0	0	0
Normal (-12dBm 15m)	medium(500ms)	0	0	0	0	0
	long(1000ms)	0	0	0	0	0
	short(100ms)	24.7163601	31.000586	35.8962677	44.4455923	61.7735791
Strong (4dBm 70m)	medium(500ms)	35.8962677	48.3148508	48.3148508	54.6361752	66.9451236
	long(1000ms)	28.3879436	38.5775751	44.4455923	48.3148508	58.508802

Appendix B: Beacon orientation - RSSI and distance averages

	Front	Back	Top	Bottom	Left	Right
Min	-86	-85	-99	-101	-95	-94
25 Percentile	-84	-83	-92	-92	-90	-92
Average RSSI Measured	-84	-83	-90	-91	-89	-91
75 Percentile	-83	-83	-89	-90	-89	-90.5
Max	-81	-79	-86	-87	-86	-86
Average Distance (M)	2.446173858	2.26561907	4.334945122	4.805408768	3.941116042	4.468231153

Appendix C: UCAS open day itinerary

Cardiff School of Computer Science & Informatics

UCAS Visit Day

Programme for applicants*:

Time	Activity	Room
10:30 - 11am	Arrival/ registration; tea, coffee, biscuits	***Seminar Room 1***
11:05am	Welcome from Director of Teaching Dr Stuart Allen	***Seminar Room 1***
11:15am	School of Computer Science & Informatics talk, by Dr Steven Schockaert	***C/2.07***
12pm	Python Lab session with Dr Will Webberley	***C/2.04***
12:50pm	Lunch and one-to-one discussions with staff	***Seminar Room 1***
1.45pm	Tour of the School and Student Union with current undergraduate students	
2:30pm	Residences DVD and Q&A	***C/2.07***
2:50pm	Admissions advice, feedback forms, final questions	***C/2.07***

There is a separate programme of activities for applicants, and for parents and guests - please ensure that you are following the correct programme (you will be guided by staff and students throughout the day)

Cardiff School of Computer Science & Informatics

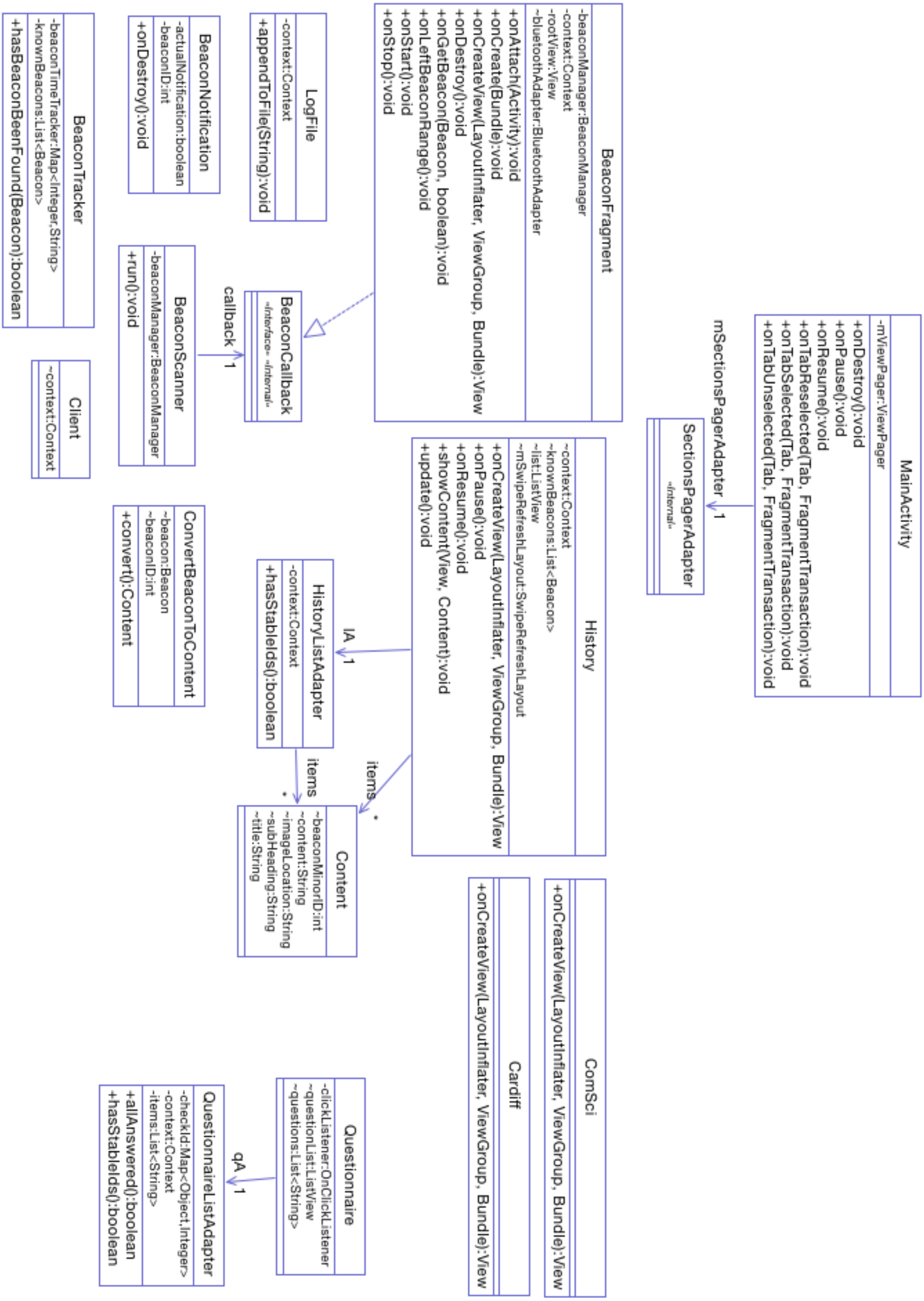
UCAS Visit Day

Programme for parents and guests*:

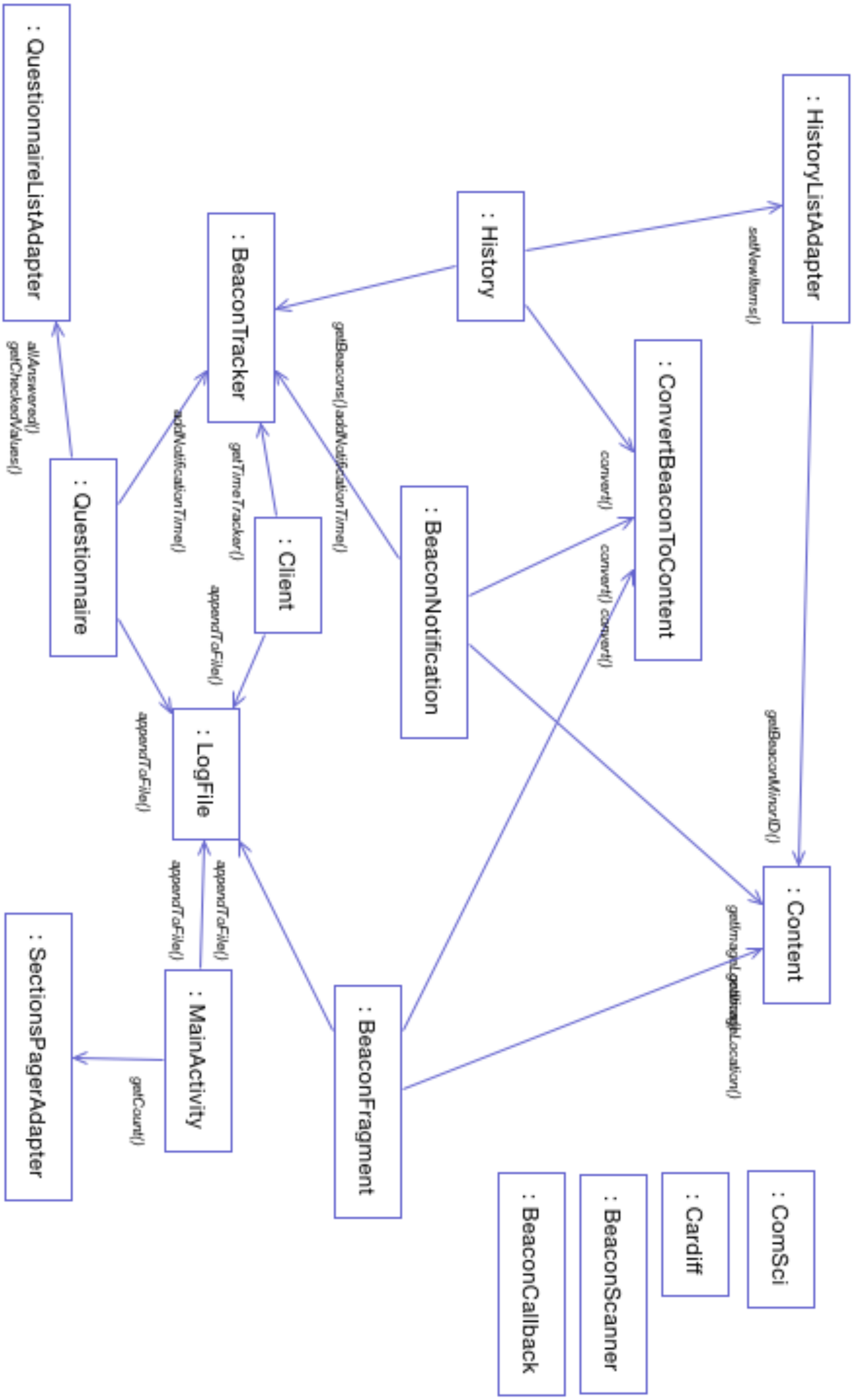
Time	Activity	Room
10:30 - 11am	Arrival/ registration; tea, coffee, biscuits	***Seminar Room 1***
11:05am	Welcome from Director of Teaching Dr Stuart Allen	***Seminar Room 1***
11:15am	School of Computer Science & Informatics talk, by Dr Steven Schockaert	***C/2.07***
12pm	School Tour	
12.20pm	Finance Talk with Siobhan Williams	***C/2.07***
1pm	Lunch	***T/0.31***
1:50pm	ImprompDo app talk with Liam Turner	***C/2.07***
2:30pm	Residences DVD and Q&A	***C/2.07***
2:50pm	Admissions advice, feedback forms, final questions	***C/2.07***

There is a separate programme of activities for applicants, and for parents and guests - please ensure that you are following the correct programme (you will be guided by staff and students throughout the day)

Appendix D: UCAS tour guide class diagram



Appendix E: UCAS tour guide interaction diagram



Appendix F: Tour Guide – Beacon recognition times

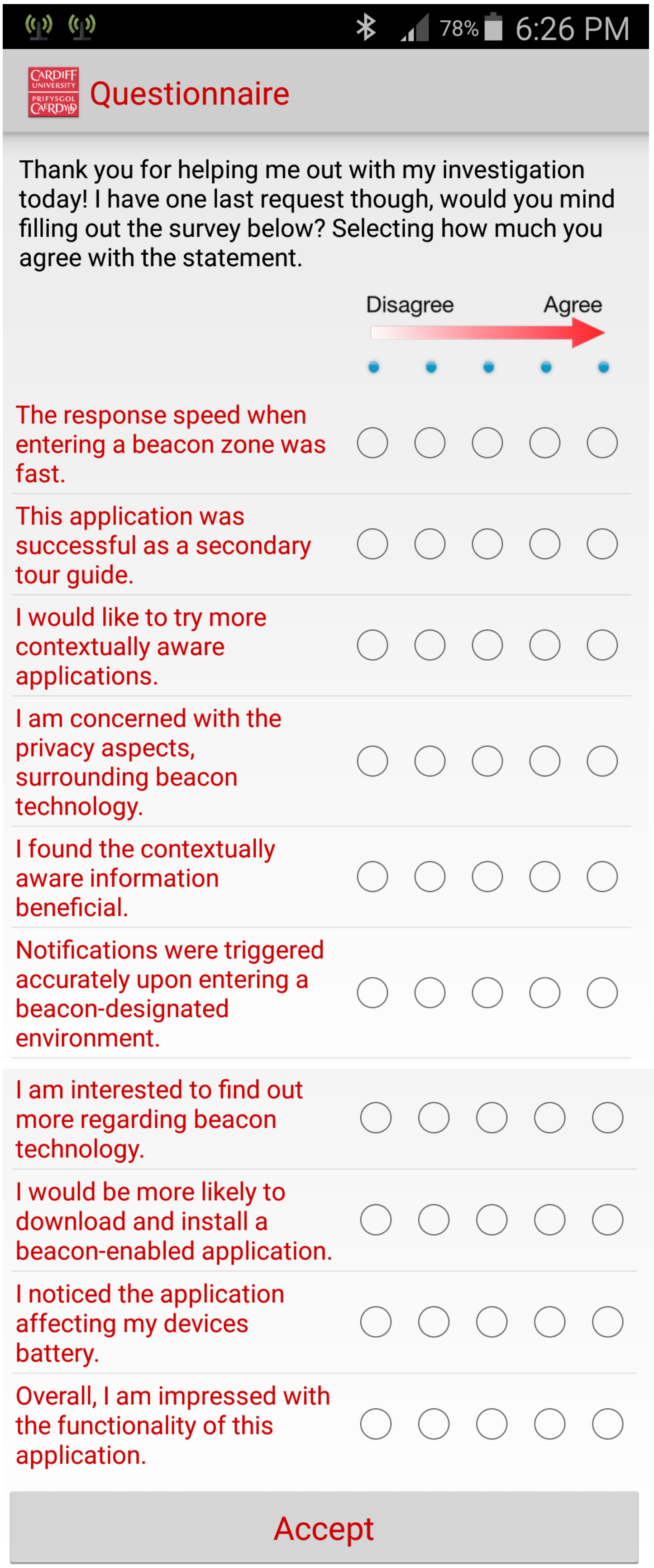
Beacon Minor	Beacon Recognised	Notification opened	Notification closed
1	11:10:39		
1	11:11:44	11:13:09	11:13:15
1	11:11:44		
1	11:12:03		
1	11:12:16	11:55:32	11:55:41
1	12:03:18		
1	12:03:32		
1	12:10:45		
1	12:11:01		
1	12:12:07		
1	12:12:28	12:12:32	
2	12:08:30		
2	12:08:39		
2	12:08:42		
2	12:09:02		
2	12:09:05		
2	13:56:24	13:56:59	13:57:10
2	13:56:58	14:11:43	14:11:56
2	13:57:53		
2	13:57:55		
2	13:57:55		
3	12:07:38		
3	12:07:40		
3	13:55:48	13:56:12	13:58:03
3	13:56:01	13:56:34	13:57:03
3	13:56:07	13:56:34	13:56:40
3	13:56:39		
3	13:56:51		
4	12:15:22		
4	12:15:31		
4	12:15:33		
4	12:15:45		
4	14:03:55		
4	14:04:15		
4	14:04:19		
4	14:04:20	14:04:25	14:04:28
4	14:04:31	14:11:25	14:11:27
4	14:05:01	14:10:25	14:11:44
5	11:22:28		
5	11:42:22	11:42:30	11:43:02
5	13:51:13	13:51:19	
5	13:52:28	13:52:32	
5	13:53:18	13:53:26	13:54:22
5	14:41:45	14:42:09	
5	14:44:11	14:48:15	14:50:02

5	14:45:00	14:51:39	14:52:06
5	14:45:01	14:45:15	14:47:07
5	14:50:01	14:50:15	14:52:07
7	10:33:31		
7	10:35:12	10:36:01	10:36:20
7	10:41:29	10:41:32	10:44:01
7	10:45:20	10:45:28	10:45:59
7	10:51:00		
7	10:55:32		
7	10:57:30		
7	10:58:32		
7	11:05:56		
7	11:08:08		
7	11:11:05		

Appendix G: UCAS open day beacon configurations

Beacon ID	Room	Power(dBm)
1	Windows Labs	-16 (7m)
2	Linux Lab	-20 (3.5m)
3	Mac Lab	-30 (1.5m)
4	Library	-8 (30m)
5	C/2.07	-16 (7m)
7	Trevithic Seminar room	-12(15m)

Appendix H: UCAS questionnaire interface

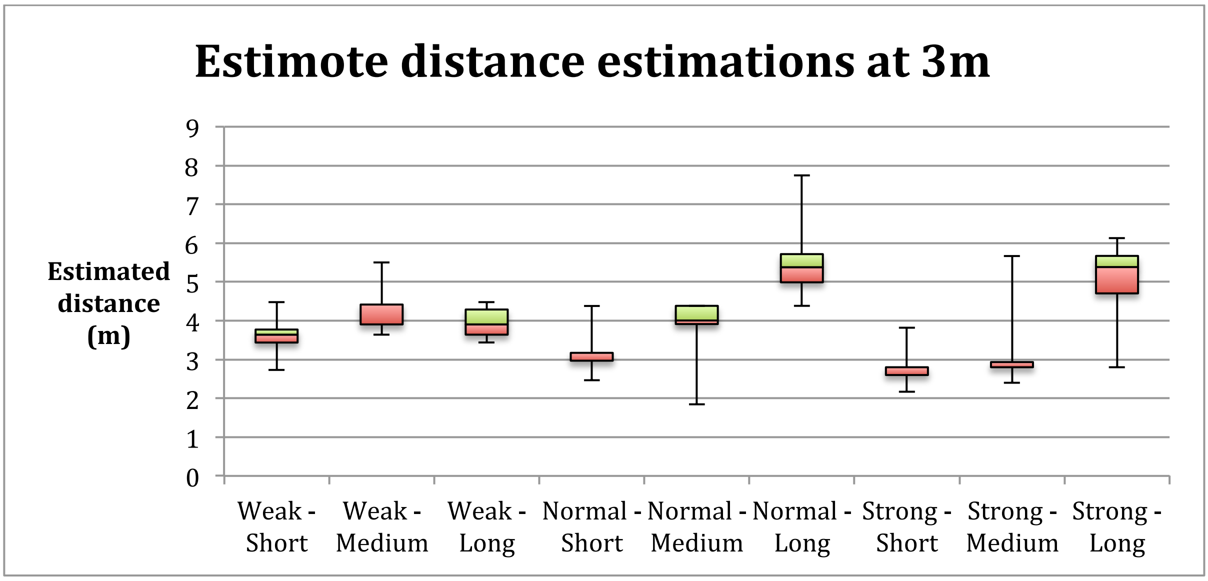


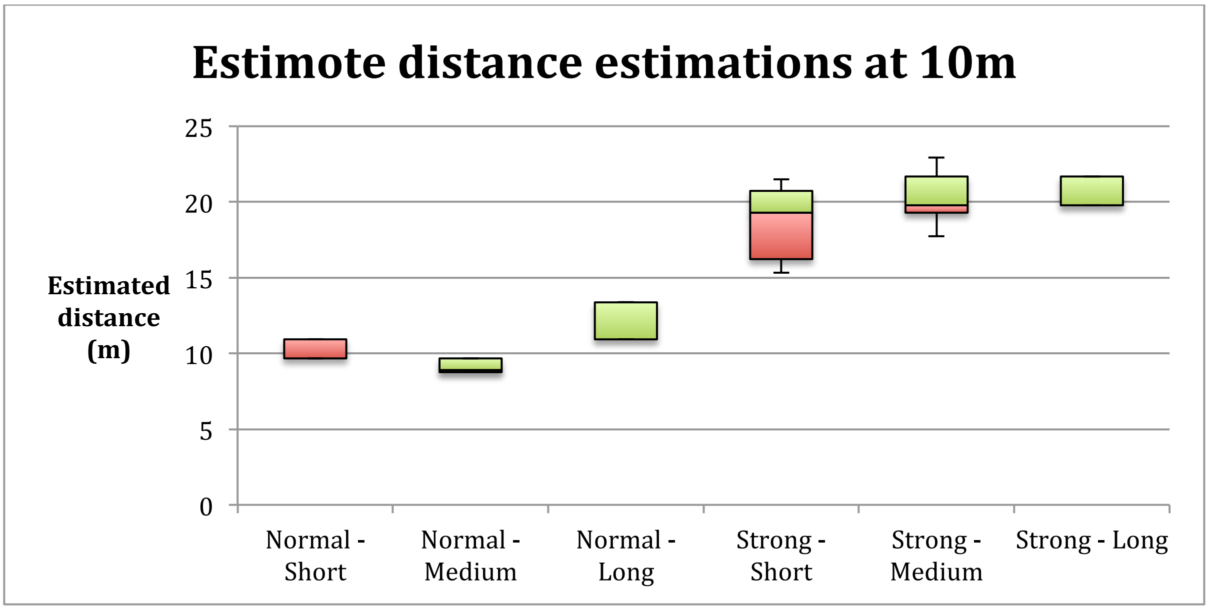
Appendix I: UCAS questionnaire results

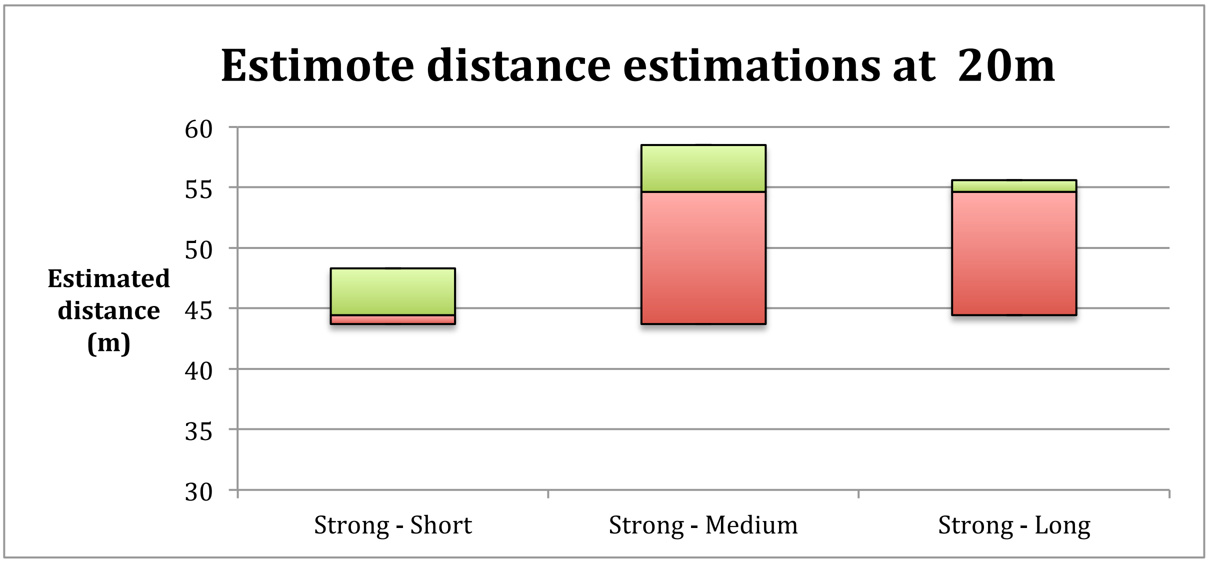
	User A	User B	User C	User D	User E	User F	Min	Max	Average
Question 1	4	4	4	4	4	4	4	4	4
Question 2	3	3	1	3	3	2	1	3	3
Question 3	3	2	4	2	4	1	1	4	2.5
Question 4	3	1	1	2	3	1	1	3	1.5
Question 5	4	3	2	3	4	2	2	4	3
Question 6	4	2	3	3	2	4	2	4	3
Question 7	4	4	4	2	3	1	1	4	3.5
Question 8	3	2	1	3	2	2	1	3	2
Question 9	2	3	2	2	2	3	2	3	2
Question 10	4	1	2	3	3	0	0	4	2.5

0 = Disagree   4 = Agree

Appendix J: Unreferenced Box chart accuracy measurements




Estimote distance estimations at 10m
Estimated distance (m)
25
20
15
10
5
0
Normal - Short
Normal - Medium
Normal - Long
Strong - Short
Strong - Medium
Strong - Long


Estimote distance estimations at 20m
Estimated distance (m)
60
55
50
45
40
35
30
Strong - Short
Strong - Medium
Strong - Long