Assessing iBeacons as an Assistive Tool for Blind People in Denmark

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Abstract

The blind community depends on sighted people for a significant amount of information and assistance. This project, sponsored by the Danish Association of the Blind, explored the ability of iBeacon technology to assist blind people while navigating indoors. Pilot testing discovered that the current iBeacon system, coupled with only the necessary Bluetooth technology, presents significant obstacles for use. Interviews with industry experts revealed that the weaknesses have been overcome internationally by blending Bluetooth with other technologies. We concluded that iBeacons have great potential as an assistive tool for blind people, but the system we tested needs significant improvements before we would advise implementing it in Denmark.

Acknowledgements

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Executive Summary

An estimated 285 million people worldwide have a visual impairment that cannot be corrected with traditional glasses or contact lenses. Of these 285 million, almost 40 million are completely blind (Pascolini & Mariotti, 2011). Research has estimated that "eighty to eighty five percent of our perception, learning, cognition and activities are mediated through vision" (Politzer, 2015). Being unable to access all the same information as sighted people puts the millions of blind people around the world at a major disadvantage. What is a simple task for a sighted person can be very difficult for someone who is blind, and blind people need assistance in many aspects of their lives.

Various assistive tools exist for blind people in navigating in unfamiliar environments, such as Global Positioning System (GPS) for outdoor navigation, white canes and guide dogs for obstacle avoidance, and Accessible Pedestrian Signals (APS) at street crossings. Each of these tools is effective, but none of them can offer any guidance through unfamiliar indoor environments. There is currently no widely used assistive tool that can, for example, locate a particular office in a large building or the correct departure gate in an airport. In instances like these, most blind people will need to ask for help from a sighted person in the vicinity. This dependence on others hinders blind people's ability to be self-reliant. During our time in Denmark, we interviewed five people with varying levels of visual impairment, and they all expressed a desire to be more independent and need less assistance from sighted people, especially when navigating through unfamiliar environments.

Our project sponsor, the Danish Association of the Blind (DAB), asked that we investigate a relatively new technology called iBeacons. An iBeacon is a small device that broadcasts information via Bluetooth. The beacon shares its unique identification number, and nearby smartphones with Bluetooth enabled can use that number to find the corresponding information stored in an online Content Management System (CMS). This information can be used in retail stores or tourist attractions, but DAB and the Living IT Lab, a non-profit organization in Copenhagen that has been working with DAB on this project, recognized the possibility for iBeacons to be used as an indoor information distribution system for blind people. For example, an iBeacon placed inside the main door of a hospital could say "With your back to the entrance door, the reception desk is to your right." This information would help a blind person orient him- or herself in a new space. Initial tests by the Living IT Lab indicated that

iBeacons have the potential to be used for applications like this, but that more research was needed to determine if they could be useful in the long term and on a larger scale.

During our time in Denmark, we were invited to observe a test of iBeacons at the offices of IBOS (the Institute for the Blind and Partially Sighted). IBOS recruited a small group of blind people to try to navigate through the building using iBeacon notifications on their smartphones. Unfortunately, the test was canceled during the first participant's trial due to technical difficulties, so we spent the day learning more about the problems the system presented during the test. We identified a few significant problems with the system in Denmark that need to be addressed, primarily relating to the notifications and the possibility of overlapping beacon coverage zones. These issues mainly cause frustration or confusion for the user, but a blind person needs very clear information in order to make use of the system.

Our research also identified that Bluetooth has some vulnerabilities that leave users' personal devices susceptible to possible attacks by malicious people. Someone with cruel intent could create inconveniences like draining the battery of the user's device, leading the user into the wrong room, or potentially something more serious. The most serious vulnerabilities in Bluetooth allow an experienced hacker to access the user's personal information or even take control of the user's device (Scarfone, 2008).

However, other organizations also working with iBeacons have managed to find ways to work around these issues. The technological and security concerns were well addressed in some successful iBeacon applications for blind people outside of Denmark. In London, a number of Underground (subway) stations have been equipped with the same iBeacons that we tested with (Stinson, 2015). The beacons can guide blind users from the station entrance to the correct train platform, and from the platform to the station exit at the destination. One blind user who tested the system stated that he felt "independent" and "empowered," and that the information presented by the beacons was so timely and accurate, it was almost like having a sighted guide walking with him (How Wayfindr guided, 2015). Another example of a successful use of iBeacons is at San Francisco International Airport (SFO). LightHouse for the Blind and Visually Impaired, a California-based organization, worked with Austrian company Indoo.rs to place over 300 iBeacons throughout SFO's Terminal 2. The corresponding smartphone application, developed from the beginning with input from blind people, has some very impressive capabilities. It can work actively, guiding the user to a specified destination, or passively, alerting the user of things like restrooms, restaurants, departure gates, and even power outlets as he or she walks through the terminal. The system is even powerful enough that a user can simply point his or her smartphone down a corridor and obtain a list of things that can be found in that direction (Iozzio 2014).

There are two main differences between the systems in place in London and San Francisco and the proposed system in Denmark. The first is in the way the beacons are related to each other. In Denmark, the beacons are unrelated - each one relays its own information to devices within its individual broadcast range. The other systems use a network of beacons. For example, in San Francisco, the airport terminal was mapped, and the beacons can work together (using triangulation, much like a GPS works outdoors) to pinpoint the user's location on that map and provide information about the immediate surroundings. Second, the system in San Francisco also uses things like the locations of known Wi-Fi networks, as well as the compass and motion sensors in most smartphones, to provide a more accurate location than Bluetooth alone could. John Worsfold of the Royal National Institute of the Blind in London states that this sort of "blending" of technologies allows programmers to take advantage of each one's strengths while diminishing the impact of their weaknesses (J. Worsfold, personal communication, April 21, 2015).

Our experiences with iBeacons in Denmark have led us to conclude that the iBeacon system as it currently stands could be significantly improved, but once these changes are made, the system could be an extremely useful assistive tool for blind people traveling in Denmark. As one of the important outcomes of this project, we suggest that DAB and the Living IT Lab blend other technologies with Bluetooth in future development of iBeacon systems for blind people. This would allow for the use of triangulation, which is much more accurate than the proximity-based location method being used currently. Blending Bluetooth with other technologies can provide a more comprehensive and functional system of beacons, which translates to more user satisfaction and more independence for blind people. Using enough beacons to implement triangulation and area mapping would also decrease the impact on the system if one beacon were to experience technical difficulties. Using a network of beacons adds security to the system, lessening Bluetooth's security weaknesses and making the iBeacon system more difficult to infiltrate. We suggest that DAB and the Living IT Lab contact LightHouse and Indoo.rs. The latter two organizations have previously worked together to create an extremely functional app and would be able to offer excellent input on the implementation of a large system of iBeacons. The Danish Association of the Blind and the Living IT Lab should continue working to implement iBeacons in Denmark because iBeacons would be a major step forward in creating a more independent lifestyle for blind people.

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Chapter 1: Introduction

Of the 7 billion people alive today, an estimated 285 million have some form of visual impairment that cannot be corrected with glasses or contact lenses (Pascolini & Mariotti 2011). Because visual impairment can range from a generally reduced visual acuity (blurriness of vision) to total blindness, each visually impaired individual faces a unique set of challenges in his or her daily life. There are numerous organizations worldwide that dedicate themselves to creating a world in which blind individuals can lead a fully uninhibited life. The Danish Association of the Blind (DAB) is one such organization whose goal is to ensure that blind people have the same opportunities as their sighted peers in every aspect of life. One way that DAB works to achieve this goal is through investigating technologies that provide accommodations to people with severe visual impairments. In recent years, many of the technologies in the organization's focus have aimed to assist in transportation and navigation (Danish Association of the Blind, 2012).

Research has estimated that "eighty to eighty five percent of our perception, learning, cognition and activities are mediated through vision" (Politzer, 2015). The millions of blind people worldwide are at a major disadvantage compared to sighted individuals. For example, traveling across a city to a store, locating and purchasing the desired item, and getting back home is a simple set of tasks for a sighted person. For a blind person, however, these tasks present a series of challenges. Navigating around a city, even a familiar one, is almost impossible for an individual with a severe visual impairment without some kind of assistive tool. Many blind people make use of white canes or guide dogs, which allow them to avoid obstacles or potentially dangerous situations and live more independently (MD Junction: Guide Dogs Compared to Canes, 2012). However, assistive tools like guide dogs and white canes do not provide any assistance in navigation (Carter et al, 2007). Global Positioning System (GPS) devices are able to display the user's location using satellite triangulation. It is a useful tool for turn-by-turn navigation and locating points of interest, and can be used in any outdoor location in the world (GPS Technology for the Blind, a Product Evaluation, n.d.). GPS could be used by a blind person in the previous example to navigate to and from the store. However, the usefulness of GPS stops once the user enters a building because its signal cannot pass through most common building materials. In addition, GPS does not provide any information about possible hazards. While there are options for blind individuals to navigate outdoors, current navigational technology is ineffective in indoor settings.

Once at the shop, a sighted person could simply see where the desired item is located, find the checkout counter, pay for the item, and exit the shop. A blind person, on the other hand, would need assistance with these tasks. Braille, a writing system for blind individuals composed of raised dots on a flat surface, has proven to be the most effective way for the blind to receive and convey information. However, according to John Heilbrunn, vice chairman of DAB, Braille is not commonly found in public areas in Denmark. Current adaptations for blind people make it easier to live a more independent life, but additional assistive devices are necessary in order to make DAB's mission a reality.

To this end, DAB has been considering implementing beacon technology in key locations within the city of Copenhagen. A beacon is a small device that wirelessly transmits a unique identification number via Bluetooth to users' devices in the vicinity. These devices utilize an application to follow that number to a specific section of an online library of information and present its findings in an accessible format (What is iBeacon?, n.d.). Beacons can be used to provide information such as the location of a particular shop in a shopping mall or train schedules in a busy station, as well as other kinds of information that blind people cannot gather on their own. A beacon application can also prompt the user to perform certain actions like choosing between a number of options or posting a check-in on a social media site. To take advantage of this technology, users can simply download an app to their Bluetooth-enabled smartphone. Beacons can be compatible with both iPhone and Android devices. This project will focus specifically on iBeacons - beacons designed to work with iPhones and other Apple devices, which are popular among blind people because of their extensive accessibility features.

In this report, we first discuss blind people's needs, current assistive tools used by blind people, and the potential of the iBeacon. Chapter 3 discusses the overarching goal of the project and the objectives we needed to fulfill to achieve the goal. It also discusses the methods we used to fulfill our objectives. Next, we present our findings from our work in Denmark and our recommendations for our sponsors as they move forward with the development of iBeacons as an assistive tool for blind people.

Chapter 2: Background

2.1 Behind the Issue: Challenges of Being Blind

Much of what we do on a daily basis requires extensive use of our sense of vision, from complex tasks like driving a car or navigating on foot around a city, to simply reading the label on a container of milk. In fact, the majority of the information typically obtained from one's surroundings is visual (Politzer, n.d.). Most people take their sense of sight for granted and would feel helpless without it. Yet, for the hundreds of millions of visually impaired individuals worldwide, this is reality (Pascolini & Mariotti, 2011). The world was designed by, and is generally geared toward, sighted people, and it is becoming harder for blind individuals to rely only on their remaining senses in order to navigate in their environments. For example, cars are getting quieter and supermarkets and shopping malls are getting larger and more complicated. In addition to these societal changes, there can be many unforeseen obstacles in any environment. Copenhagen is a city with a high volume of bicycle travel, which creates obstacles for blind people. According to John Heilbrunn, Vice Chairman of the Danish Association of the Blind, bicyclists are quieter and harder to hear than automobiles, and cyclists, like drivers, often ride while distracted, listening to music or using their mobile phones. He also states that there are often bikes parked haphazardly on sidewalks, creating additional hazards for blind pedestrians (personal communication, February 3, 2015).

While assistive devices exist to assist blind individuals in finding their way around their world, these tools have significant limitations. Addressing these limitations is important in working toward an independent life for blind people. One of the biggest challenges that visually impaired people face is navigation. There are assistive navigational tools, such as GPS devices, for outdoor use, but they do not work well in indoor environments. A recently developed technology - the iBeacon - could fill the gap left by GPS's inability to function indoors. The iBeacon, given its proven effectiveness indoors, presents itself as a viable potential solution to the problems presented by other commonly used assistive devices. This chapter outlines the challenges faced by blind people, describes a number of assistive devices used to combat these challenges, and discusses iBeacons' potential to provide enormous assistance to the blind community.

2.2 Definition of Visual Impairment

An individual's level of visual acuity, defined as the smallest detail that he or she can see clearly from a given distance, is usually quantified by an acuity fraction. This acuity fraction compares an individual's vision to a reference standard, 6/6 meters (or 20/20 feet in imperial units). For example, if an individual sees at a level of 6/60, the smallest detail that he or she can see at 6 meters could be seen by the standard 6/6 eye at 60 meters (Watt, 2003). The acuity fraction refers only to an individual's ability to see high-contrast letters at specified distances, not to the ability to perceive larger objects or things with lower levels of contrast (such as steps or curbs). It is also not an indication of how much effort he or she must exert to see that detail, or of the relative strength of each individual eye (Watt, 2003). A severe level of visual impairment can have a drastic negative effect on a person's ability to live an independent life.

"Visual impairment" is a broad term, covering a wide variety of vision problems that severely impact one's ability to function in normal daily tasks and cannot be corrected with traditional glasses or contact lenses (Partially Sighted, n.d.). This can be further broken down into a number of categories: general reduction in visual acuity, reduced size of the field of vision (e.g. tunnel vision or central field loss), a combination of reduced acuity and reduced visual field, and blindness (Carter et al. 2007). "Blindness" can be subdivided into two classifications. Some blind individuals have a sense of light and dark - this is known as having light perception. A person who is blind but has light perception is unable to see any figures, but can tell whether or not the sun is shining or determine the general direction of a bright light. Others who are blind have no sense of light at all (Partially Sighted, n.d.). Such severe visual impairments cause blind individuals to require significant assistance in order to overcome many of the challenges they face.

2.3 Current Tools to Assist Blind People in Navigation

There are a number of helpful assistive devices that allow blind people to navigate to their destination safely. Two of the most well-known personal assistive devices are white canes and guide dogs. Each of these options has benefits and drawbacks, and an individual's choice between the two is usually a matter of personal preference. Architects and designers have also provided assistive tools in buildings and outside on the street to help blind people find their way more comfortably. Some examples of the assistive devices that are used outdoors are tactile arrows, tactile maps, auditory signals at street crossings, and GPS systems. Below, we discuss each in more detail.

2.3.1 White Canes and Guide Dogs

The "white canes" used by those who are visually impaired are long white rods that help blind users detect obstacles in their path and identify to the public that the users are blind. Tommy Edison, a blind man who posts videos on YouTube about life without vision, explains how he uses his cane when he walks: "When I put my right foot forward, I put my stick on the left [about shoulder width] and then when I put my left foot forward, I would my put my stick on the right" (Edison, 2014). This technique allows him to walk confidently knowing that his cane will contact any obstacle before he does. On average, white canes are a much more affordable option compared to other assistive devices like personal assistants. An example of a typical white cane is pictured in Figure 1 below.

Figure 1: Example of a White Cane (Jacobsen 2013)

Even though they are portable and inexpensive, some blind individuals do not like using white canes because they can easily get caught in cracks or on other objects. One member of an online blind support group said that "the cane hits obstacles rather than avoids them," which significantly slows down travel (MD Junction: Guide dogs Compared to Canes, 2012). White canes are useful in detecting stationary objects directly in front of the user, but a cane can do nothing to protect its user from an oncoming object like a car or bike. Some blind people feel that canes create a social barrier, making others less likely to approach the user of a cane. This could also be to the user's advantage - people moving out of the way helps create a clear path in which to walk.

Guide dogs have some significant benefits over white canes, but require more care and a higher monetary investment. Currently, there are approximately 260 trained guide dogs used by blind individuals in Denmark (United Nations Convention, n.d.). Guide dogs have a harness strapped to their body with a handle connected to their back and a leash connected to their collar. Either the handle or the leash can be used to control the dog in the way that is most comfortable for the user. Figure 2 (below) depicts a guide dog with both a harness and a traditional leash.

Figure 2: Guide Dog with Leash and Harness (Hughes 2013)

The support group post continues to discuss the benefits and drawbacks of using a guide dog through sharing testimonials from blind people. According to the post, some advantages of a guide dog over a white cane are increased speed, companionship, increased safety, and approachability (Guide Dogs Compared to Canes, 2012). Since guide dogs are highly trained to recognize and avoid unsafe routes, blind people can navigate quickly and more confidently knowing that their dog will lead them away from potential obstacles, including moving objects and harmful situations. However, guide dogs are not infallible when it comes to safe navigation.

They react to commands from their owner, but since they can only learn around 30 spoken commands, most of the safety choices are up to the discretion of the dog.

Perhaps the biggest advantage that guide dogs have over white canes is the element of companionship they can provide to their owners. One member of the Retinitis Pigmentosa support group mentions that after she began using a guide dog, more people talked to her on the street. The first comment was typically how cute or amazing the dog was (MD Junction: Guide dogs Compared to Canes 2012). Whitmarsh's study also found that "one out of five guide dog owners feel other people are more friendly towards them and nearly one out of ten owners believe that they are offered more help when accompanied by their dog" (2005, p.15). Consequently, as John Heilbrunn explains, some guide dog users feel that people pay more attention to the dog than to the user. Guide dogs can be distracted by unknowing passersby who try to pet or call out to the dog. A distracted guide dog could fail to notice an obstacle in the path and lead its owner into a potentially hazardous situation. Overall, though, guide dogs are useful companions for blind individuals who wish to live more independently.

2.3.2 Accessible Pedestrian Signals (APS)

Guide dogs and white canes are helpful in avoiding obstacles, but both are meant only for detecting hazards in the immediate vicinity of the user. They are unable to navigate on a long journey or recognize when it is safe to cross a street (Carter et al, 2007). Technologies known as Accessible Pedestrian Signals (APS) exist to help visually impaired individuals cross streets. The two most prominent examples of APS in Denmark are tactile arrows and audible signals. There are guidelines regarding the arrangement of these signals in an effort to make them as helpful as possible to those who use them to navigate. For example, poles with crosswalk buttons must be within specified distances of the curb and crosswalk, and pushbuttons (the buttons used to request a walk signal) must be on the side of the pole closest to the corresponding crosswalk. In addition, at a corner, pushbuttons and their respective crosswalks must be distinct enough to avoid confusion (Carter et al. 2007). A diagram depicting these guidelines can be seen in Figure 3 below.

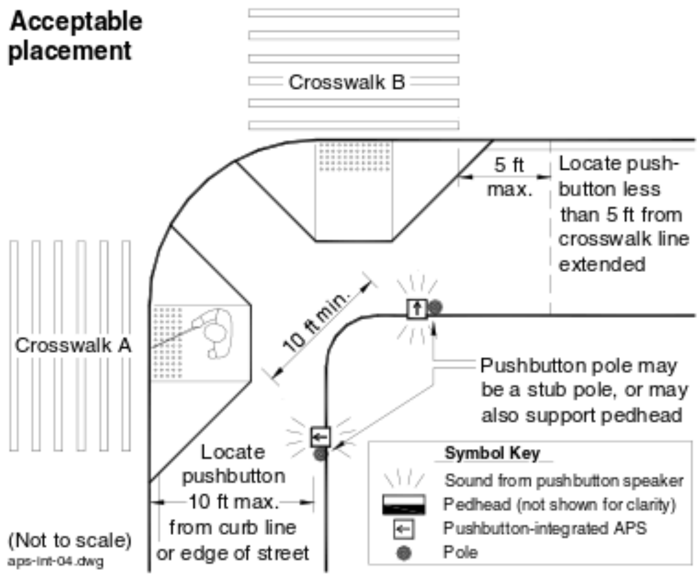

Figure 3: Diagram of Placement Requirements for APS devices (Carter et al.)

In addition to strategic placement of crossing signals, tactile arrows are also present at most crosswalks in Denmark. The tactile arrows used in Denmark consist of a raised metal bar on the top of the box on each crosswalk pole. The bar is aligned with the direction of the crosswalk and provides some information about the crossing. The arrow has a raised portion at the end signifying the other side of the street. There can also be bumps in the middle of the bar indicating medians that will be encountered before reaching the other side of the street (Vejdirektoratet, 2006). An example of a Danish tactile arrow is pictured below in figure 4.

Figure 4 depicts a set of tactile arrows representing two street crossings from a median. Each arrow points in the direction of the corresponding crosswalk, and the raised portion at either end signifies the sidewalk on either side of the street. By feeling the arrow with his or her hands, a blind pedestrian standing on this median would be able to determine that there are no medians or intermediate crossings in either direction.

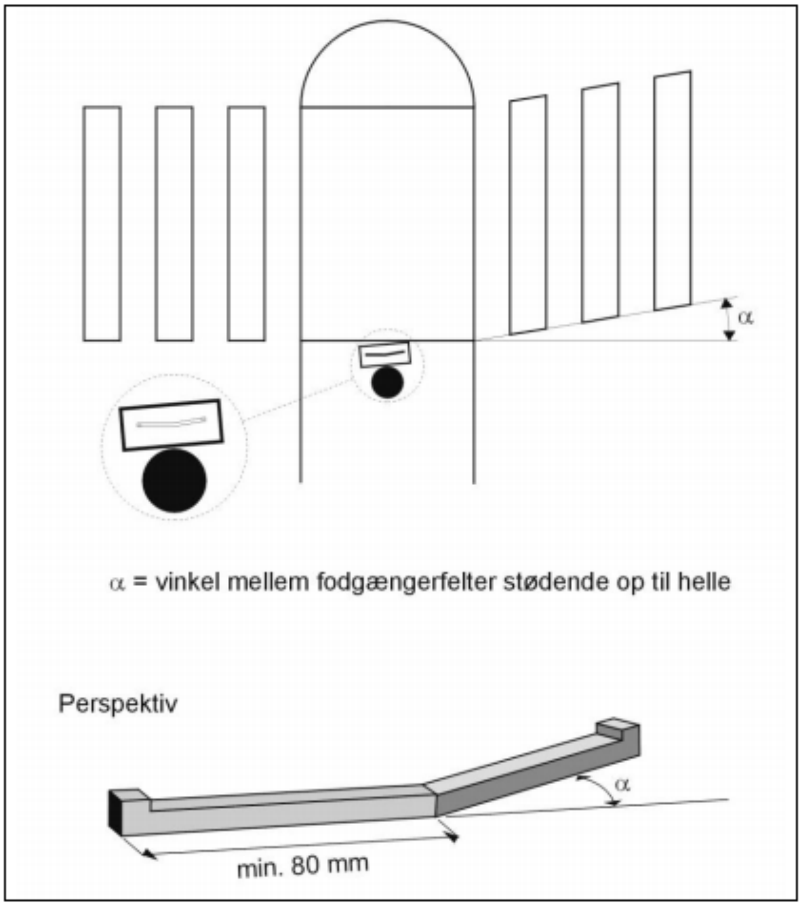

Figure 4: Diagram of a tactile arrow representing two crossings (Vejdirektoratet 2006)

Tactile arrows like the ones used widely in Denmark are useful in providing basic information about the direction of a street crossing as well as any obstacles that might be encountered on the way. However, there is more than just a direction to each crossing. Each street has a different arrangement of lanes for cars, buses, and bicycles. For this reason, some countries have equipped their street crossings with tactile maps, raised maps that represent the street crossing (Figure 5). By touching the map, a blind person can discern how many lanes are on the road, what kind of traffic (car, bus, bike) is present in each lane, and the direction in which the traffic in each lane is travelling (Carter et al. 2007).

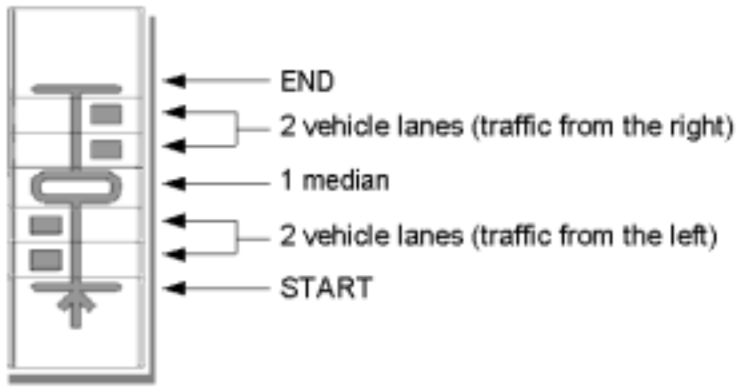

Figure 5: Diagram of a tactile map representing a street with two lanes in each direction (Carter et al.)

The intersection depicted by this tactile map shows that there are two lanes of traffic in each direction, separated by a median. A blind person would gather this information by touching the map with his or her fingers, starting at the bottom. First, he or she would encounter the two lanes of vehicle traffic from the left, then the median, then the two lanes of traffic coming from the right. Since every street crossing is unique, tactile maps are useful to provide blind people with information about each crossing as they encounter it.

Tactile arrows and tactile maps are excellent tools to display information about an intersection, but, like guide dogs, do not generally alert pedestrians when it is safe to cross the street. Most intersections in Copenhagen make use of audible signals, or beepers, to indicate when it is safe for pedestrians to begin crossing the street. There is a constant series of beeps, which become more frequent when pedestrians have the right of way to cross. The signal is designed to be heard within 2-4 meters of the street crossing, though the exact direction from which the signal is coming may be unclear, especially in areas with a lot of crosswalks or with high levels of ambient noise. This problem is addressed at some intersections by the use of audible signals with adjustable volumes; the signals are capable of adjusting themselves to account for other noises in the vicinity (Carter et al. 2007). Signals like these enable the blind to know when it is safe to enter an intersection, just like a lighted walk signal does for sighted people. The information provided by the various APS technologies in use in Denmark directly address the challenge of crossing streets faced by blind people.

2.3.3 Global Positioning System (GPS) Technology

Accessible Pedestrian Signals are immensely helpful for informing visually impaired persons when it is safe to cross a street, but it is also important that the blind person in question knows which street he or she needs to cross in order to get to their destination. Another kind of technology that is used to help blind people get around is Global Positioning System (GPS). This technology uses information from satellites to pinpoint a user's location and provide that position through various smartphone applications, such as Google Maps, or dedicated GPS devices. Positioning systems like GPS are beneficial in the sense that they can provide turn-by-turn instructions based on geographical location from the start of the journey to the end. However, the technology has several important limitations, the most significant of which is that it cannot be used indoors (GPS Technology for the Blind, a Product Evaluation, n.d.). In addition, the technology can sometimes misrepresent a device's location. As a navigation tool, GPS technology can provide many important benefits to the blind, but its limitations need to be considered when using it.

2.3.4 Other Assistive Tools

Navigating around a city is not the only everyday task for which visually impaired people require assistance. They may also need help with general household tasks, and in their own home a sighted person may not always be there to offer assistance. One program that a blind person could use in such a situation is a smartphone app called Be My Eyes. The app connects visually impaired people with sighted people all over the world. To use the app, a blind person indicates that he or she needs help, and the app sends a live feed from the phone's video camera to a sighted person who has agreed to provide assistance (Adamczyk 2015). An app like this could be used by a blind person who, for example, needs help determining what the expiration date is on a container of food or what the total balance is on a bill. As of March 2015, the app is only available for iPhone, but according to creator Hans Wiberg, an Android version is also under development (Adamczyk 2015). As of March 30th, 2015, there were over 17,000 visually impaired people using the app and over 190,000 sighted volunteers available to help them.

Another example of a software program assisting the blind is Dragon Dictation, which is a speech-to-text program that is available across many platforms and can do things such as post status updates on social networks and send texts and emails (Dragon Speech Recognition

Software). Programs like these allow blind individuals to be more independent and not require the constant assistance of a sighted individual to get information from the world around them or to put their own ideas on paper.

2.4 iBeacon Technology

Many assistive devices exist to assist the blind community in completing their daily tasks. Each device fulfills a specific need for the blind community, but an area in which they all fall short is in providing information about the user's immediate surroundings, especially in an indoor environment. The expansion of indoor spaces like grocery stores and shopping malls has increased the need for a system that can provide this kind of information that could otherwise be gathered visually. One possible solution to this problem is iBeacon technology. An iBeacon is a small piece of hardware that can be mounted on a structure like a wall or post. It constantly transmits an identification number via Bluetooth to enabled devices in the vicinity that are using the corresponding app. The app then uses that number to access the appropriate information stored in databases either online or within the actual app. This information could be as simple as the location of a restroom in a restaurant or as complex as a list of arrival and departure times for various trains and buses at a busy station (What is iBeacon?, n.d.).

iBeacon technology is fairly new and has not been implemented on a large scale anywhere in the world, but opportunities exist to use iBeacons within the city of Copenhagen. iBeacons are tools that can be used in many different ways in order to make life more convenient. They can be used by members of the general public to facilitate self-guided tours, check in on social media sites, or to navigate in an indoor setting. Business owners can implement iBeacons for help with locating customers within their facilities, sending messages to customers, or even to enable faster and easier payments (CapTech, 2014). Some key areas in which iBeacons have the potential to be helpful are healthcare, consumer packaged goods, and retail use. iBeacons may also be useful to those who use public transportation. One potential example is at a bus station, where an iBeacon can send information to a smartphone or another Bluetooth-enabled device and prompt the user to choose or search for a destination. Once the user has indicated his or her selection, the app could display (visually or audibly) the correct bus's estimated arrival time and scheduled time of departure from that bus station. Once on the bus, the app would be able to alert the rider when the bus is approaching the user's destination.

Though there are other applications that work with public transportation systems, many have not been designed with blind people in mind and therefore may not work very well with the accessibility features present on most smartphones.

Currently, iBeacons are being used in retail stores to give customers information about products or even special deals or discounts (CapTech, 2014). Self-guided audio tours in places such as museums are another example of an application of iBeacons (Elgan 2013). These tours would involve the use of iBeacons as an indoor positioning system (IPS) and would be similar to the way GPS uses satellites: the user's location is pinpointed based on his or her relative distance from iBeacons in the area. In this scenario, audio cues with information about points of interest would play when the user enters a pre-defined area. This idea can be easily adjusted for use by visually impaired individuals by presenting information that relates to important facilities or services.

iBeacons have several advantages over the most commonly used assistive tools for the blind community. Due to the way they are intended to be implemented, iBeacons are ideal for providing localized information. In this way, those relying on the system for navigation can get detailed information about their immediate surroundings as it becomes relevant. Also, unlike GPS technology, iBeacons can be applied to both indoor and outdoor settings (GPS Technology for the Blind, a Product Evaluation, n.d.; Elgan 2006).

iBeacon technology does, however, have a handful of hardware limitations. Beacons that run on AC power exist, but the batteries in those that can't be plugged in must be replaced every 2-3 years, which would become a large undertaking if the devices were to be implemented in a variety of locations across a city. Additionally, interference from various sources can obstruct that transmission of the information from the beacon to the listening device (Binsabbar, 2014). Concerns about security are also a problem. iBeacons make heavy use of Bluetooth technology, which is notorious for its issues with performance and security (Hager et al, 2003). Bluetooth is vulnerable to malicious attacks, which can result in problems ranging from minor inconvenience to more dangerous consequences, and these concerns must be taken into account when considering an implementation of iBeacons.

2.5 Our Project

The Danish Association of the Blind (DAB), founded in 1911, is an organization completely run by blind individuals, that "works for equal rights and inclusion of its members in all areas of society" (Danish Association of the Blind, 2012). The association has about 9,000 members, all with a visual acuity of 6/60 or lower (J. Heilbrunn, personal communication, February 3, 2015). Current assistive tools leave something to be desired in the realm of indoor navigation. DAB, in partnership with the Living IT Lab in Copenhagen, has been exploring the feasibility of implementing iBeacon technology in key locations in the city, such as train stations and major public buildings. DAB has asked us to investigate how well the capabilities of iBeacon technology can satisfy the needs of the blind community in Denmark, and to make a recommendation about whether or not there are significant barriers impeding the large-scale implementation. The next chapter outlines our methods for accomplishing this goal.

Chapter 3: Methodology

The goal of this project was to assist the Danish Association of the Blind in assessing the ability of iBeacons to be utilized by blind and low-vision individuals for indoor navigation within the city of Copenhagen. We investigated the technical and social opportunities and barriers that exist in relation to iBeacons as an indoor information distribution system.

To achieve this goal we focused on the following objectives:

1. Determine the implications, opportunities, and barriers regarding the introduction of iBeacon technology in Copenhagen
2. Understand the informational needs of the blind community in Denmark and connect these needs to the potential of iBeacon technology
3. Analyze the current technical, social, legal, and economic state of the system and its readiness for implementation on a local level
4. Address potential concerns for the project to consider as it move forward from here

The methods we used to complete these objectives are detailed below.

3.1 Objective 1: Determine the implications, opportunities, and barriers to the introduction of iBeacon technology to the public

Beacon technology is relatively new, and for this reason it was challenging to locate scholarly research on the topic. During our initial research, however, we came across a webinar called 'Demystifying iBeacons' by CapTech, an American consulting company for systems integration and data management. CapTech has been working with iBeacons to discover the potential of the technology. To address the difficulties we were having understanding iBeacons and how they work, we reached out via email to Jack Cox and Mark Badger, the two iBeacon technology experts from the webinar, and conducted semi-structured interviews with them. Cox's work focuses on the technological side of iBeacons, while Badger's focus is on the user interface - the interaction between the user and the technology. Some questions that we asked both of them are listed below (Refer to Appendix A for all the questions we asked Jack Cox and Appendix B for all the questions we asked Mark Badger).

1. How long have you been working with iBeacons?
2. What are the pros/cons of using iBeacon CMS (Content Management System on the Web)?

3. What are the pros/cons of using iBeacon mobile Apps?
    a. Missing some features?

We also worked closely with Stefan Schmidt and Mads Andersen, researchers at the Living IT Lab in Copenhagen. The Living IT Lab is a non-profit organization dedicated to connecting innovative technologies with the needs of society, specifically those with physical, mental, and cognitive disabilities. Schmidt, the project coordinator, has been investigating how iBeacons may be able to provide assistance to disabled people, specifically those with visual impairments and learning disabilities. Andersen is a graduate student intern at the Living IT Lab who is currently formulating a business model for iBeacons. They provided us a draft of their report on iBeacons as a navigational tool to aid people with disabilities, and we used a translated version of the document to learn more about iBeacons and what they can do for the blind. When we arrived in Denmark, we were able to learn more about their project during our first week of work. We had a discussion with them about their initial findings about iBeacons, and how the system may be able to assist the blind. After receiving the new information and many days of research, we constructed another semi-structured interview with them, but with more specific questions we had about iBeacons (Refer to Appendix C). In these instances, we believed that semi-structured interviews were the best option because they allowed us to ask for clarification on any ambiguities, or to diverge slightly from the planned questions to get more information about something new that was mentioned.

3.2 Objective 2: Understand the informational needs of the blind community in Denmark and connect these needs to the potential of iBeacon technology

Currently, the majority of iBeacon usage is for retail purposes, but a number of companies and organizations have been exploring other ways iBeacons can benefit society. A California organization called LightHouse has placed iBeacons throughout an entire terminal of the San Francisco Airport (SFO) using an app designed with input from blind people. Initial test results were promising, and they plan on expanding the beacons to the rest of the terminals in coming years. The Royal London Society for Blind People has implemented iBeacons on a trial basis in a number of London Underground stations and has gotten positive results from the blind people who have tested the system. We reached out to and interviewed Bryan Bashin, the CEO of LightHouse. A list of questions we asked him can be found in Appendix D. We also reached out to Katherine Payne of RLSB, who was involved in the iBeacon installation in the Underground stations. We unfortunately did not hear back from her, but were able to speak with John Worsfold, a representative from the Royal National Institute of Blind people in London, about the implementation of iBeacons in the London Underground system. A list of questions we asked Mr. Worsfold can be found in Appendix E.

We also conducted interviews and discussions with a number of DAB employees who are blind. We discussed their use of assistive tools when navigating in unfamiliar environments, as well as the kinds of information that they have trouble gathering from their surroundings. The goal of these semi-structured discussions was to better understand where there are gaps in the information blind people can acquire independently and to determine if iBeacons could be useful to fill those gaps.

3.3 Objective 3: Analyze the current state of the system and its readiness for implementation on a local level

Stefan Schmidt and Mads Andersen, the researchers from the Living IT Lab, provided us with three iBeacons, produced by a company called Estimote, that we used for our own small-scale tests of functionality and security. We connected a smartphone to the beacons using Bluetooth and tested how well the iBeacons measured the phone's distance from the beacon, as well as the beacons' ability to notify the user when he or she is approaching the beacon. We also did some research related to various weaknesses of Bluetooth, on which beacons rely heavily to provide information to users. This focused on three possible weaknesses of the system that someone with malicious intent may attempt to exploit. The first instance involved having a Bluetooth enabled device pretending to be an iBeacon. The second focused on potential attacks aimed at the user with the intent of denying them the ability to use their devices. Finally the third involved a series of attacks focused on the ability of a phone to operate properly in the beacon-enabled state while under attack.

To gain firsthand experience with a working system of iBeacons, we were invited to observe a test at IBOS (the Institute for the Blind and Partially Sighted) on April 17th, 2015. Originally, we had planned on following blind participants as they navigated through the building using the iBeacons for guidance and interviewing them after they were done. We also planned on holding a focus group with all of the participants after they had all completed the trial to find out what they liked about the system, what they disliked about it, and if they could suggest any improvements to the user interface or to the information presented by the beacons. Unfortunately, due to a number of unforeseen technical difficulties, the trials were cancelled and we instead experimented with the system ourselves. We used our own smartphones to connect to the beacons, learning more about the technical difficulties that had been experienced and trying to identify more that may not have been noticed due to the tests not being completed. Our investigations at IBOS gave us the opportunity to observe how a system of iBeacons is set up, experiment with the signal strength and broadcast intervals of a series of beacons, and experience the system's current state firsthand.

3.4 Objective 4: Address potential concerns for the project to consider as it moves forward from here

Based on the results of our research, interviews, and product tests, we have compiled a summary of our findings specifically concerned with the drawbacks and risks of the technology that we feel should be addressed before we would feel comfortable advising a widespread implementation of a beacon system. We also created a series of recommendations for DAB, suggesting possible improvements to the current approach to iBeacons as an assistive tool for blind people that would make the system of iBeacons more reliable and effective for those using it. The next chapter discusses what we found as a result of these methods.

Chapter 4: Findings

During our time in Copenhagen, we conducted interviews, research, and testing to determine if iBeacons could effectively assist blind people in indoor navigation and if any improvements could be made to the approach of the project. Using the methods described in the previous section, we have collected a number of key findings that are detailed in this chapter. The next chapter will cover our recommendations and conclusions.

Finding #1: The blind community is dependent on outside sources for a significant amount of their navigational and informational needs.

As a blind person, it is often necessary to ask a sighted person nearby for navigational or informational assistance. In April 2015, we interviewed five DAB employees with visual impairments ranging from low-vision to complete blindness about the assistive tools they use in their daily lives, how they navigate through unfamiliar environments, and how they gather information from their surroundings. All five respondents were in agreement that even though they regularly make use of assistive devices, they depend on sighted people for a significant amount of assistance and information.

When walking in unfamiliar environments, the five people we spoke to all use a white cane to help avoid obstacles and to notify nearby pedestrians and cars that they are blind. One interviewee, Jannie Hammershøi, also uses a guide dog in some cases. Most of the respondents prefer not to use GPS devices to navigate, instead preferring to prepare for their trip beforehand and ask for help along the way if needed. Christian Bundgård used the example of navigating down an unfamiliar street in search of a particular shop. Once he knows he is on the right street, the way he usually goes about finding his destination is to simply enter a shop on the street and ask if he is in the right one. If he is not, he asks which direction and approximately how far he needs to walk to get to where he wants to go.

Blind and low-vision people must rely on sighted people for other reasons as well. For example, Helle Riley and Ask Abildgaard discussed the assistance they need while grocery shopping. Due to weekly sales and seasonal rearrangements, the layout of even a familiar grocery store could be different each time they enter it. Neither Helle nor Ask brings a sighted companion to the grocery store for every shopping trip, but both acknowledged that it is always necessary to ask for help from sighted people in the vicinity (either from store employees or fellow shoppers) to determine, for example, what variety of apple they are holding or whether they have picked up skim milk or whole milk.

The last question we asked all of the respondents was about “fantasy” assistive devices - devices that are not currently available but that the participants would like to have. Two people immediately replied that they would like the ability to drive - Jannie Hammershøi imagined a car that can listen to where she wants to go and drive there on its own. Helle Riley stated that a car would allow her to travel on her own schedule and not rely on trains or other people to get where she needs to go. John Heilbrunn described his ideal device, a handheld machine that could read various kinds of text, such as food labels, expiration dates, train timetables, and posted signs on doors and windows. He said that this device would allow him to be less dependent on people in the vicinity, whether they are family members or strangers on the street.

Ask Abildgaard explained that “being blind is an informational disability [and] an orientation disability…” and that blind people need help to get an idea of where they are so they can determine where they need to go. Other participants echoed this idea, stating that they would appreciate the ability to be more independent in their everyday lives.

Finding #2: iBeacon technology has the potential to be a valuable aid to the blind community in Denmark.

In 2013, Apple Inc. introduced iBeacons as a way for retail companies to improve their customers’ transactions. However, a number of companies have realized iBeacons’ potential application to those with various physical, mental, and cognitive disabilities. The staff of the Living IT Lab in Copenhagen has been investigating iBeacon technology in this context, specifically focused on those with visual impairments and learning disabilities. According to John Heilbrunn, traveling can be very difficult for a blind person. Many different technologies exist to assist blind people in overcoming the challenges that come with navigating, especially through unfamiliar spaces. Unfamiliar indoor spaces are one of the most difficult places for blind people to navigate safely and quickly because no technology is currently available to effectively provide information indoors.

About a year ago, the Living IT Lab discovered iBeacons and hypothesized that they could help people with visual impairments and learning disabilities live a life with fewer challenges. They bought some iBeacons made by a company called Estimote and started to explore the possibilities of what iBeacons can do. After months of research and working with the iBeacons, they designed and tested a number of scenarios at both the Danish Association of the Blind’s offices and the offices of the Institute of the Blind and Partially Sighted (IBOS) in November of 2014. One scenario involved participants walking down a hallway at IBOS and being notified of meeting rooms as they passed by them. This scenario most closely mirrors the proposed use of the beacons on a larger scale: providing relevant information about the immediate surroundings. A total of six similar scenarios aimed at blind people were conducted during this testing day. Below is a photo showing an iBeacon placed at IBOS for testing. The iBeacon is the small blue object directly above the sign for the restroom.

Figure 6: Example of an iBeacon used for testing

The goal of their project, "Beacons i social IT-løsninger (iBeacons in Social IT solutions in English)," was to gain experience and knowledge of iBeacons and develop a final product that can be installed and utilized to help blind people with indoor navigation. After about eight hours of testing with ten blind and partially sighted participants, they were able to come to the conclusion that iBeacon technology has the potential to increase independence and safety for blind people in indoor settings, but that more research and testing was needed before an investment was made. Most of the test subjects indicated that they found the information presented by the beacons useful and that they believed they could use iBeacons to their advantage (Schmidt, 2014).

Stefan Schmidt, the project coordinator at Living IT Lab, analyzed the data and started brainstorming more ways iBeacons could assist blind people. One example includes placing a beacon outside a building's main door which sends the name of the company and the main telephone number to the user, giving him or her an opportunity to call for assistance. The original tests used proximity-based information, meaning the iBeacons would send information to the phone about the local surroundings once the phone came within a certain radius of the beacon. The staff of the Living IT Lab is also considering using beacons that can produce audible signals.

These audio beacons say information out loud, such as “toilets located here,” or can simply play a tone when activated, which would eliminate the need for the beacons to provide orienting information (e.g. “if your back is to the main entrance door, the restrooms are to your right”). A blind user would receive a notification that, for example, there are restrooms nearby. If interested, he or she could tap the notification and the beacon near the restroom would make a sound. The sound could be used (and repeated as many times as necessary) to locate the bathroom regardless of the user’s relative position and orientation. Unfortunately, audio beacons like this are still in development, so we were unable to do anything more than observe a demonstration of a prototype and provide initial thoughts.

The tests and research performed by the Living IT Lab determined that iBeacons have the potential to help blind people navigate safely. We continued to investigate how they can be used efficiently. The Danish Association of the Blind requested that we move forward from the Living IT Lab’s findings to weigh the benefits and drawbacks of using iBeacons as an aid for the blind community.

Finding #3: Bluetooth technology has some limitations that could hinder its ability to be used in the proposed way

Our initial research identified that Bluetooth signals, which iBeacons use to connect to users’ mobile devices, can be interrupted by a number of common substances. Two of the most commonly mentioned materials (and the most relevant to our project) are metal and water. The majority of buildings, including public transportation spaces like train stations and airports, have a high metal content. The metallic structures can alter the wavelength of the Bluetooth signal, causing the message to be delivered more slowly or not at all. In addition, an area like a train station is often crowded with people. The human body is nearly two-thirds water and can weaken the Bluetooth signal from the iBeacons (S. Schmidt, personal communication, March 27, 2015).

It is also important to consider that, depending on the way the system is set up and the iBeacons are laid out, maintenance may be a rather large and complicated undertaking. The batteries in iBeacons can only last about two years, depending on the signal strength and broadcast settings. Finding beacons with low batteries and replacing them can be tedious, but it is extremely important that all the beacons are functioning in order to provide all relevant information to users (S. Schmidt, personal communication, April 17, 2015).

Furthermore, the way Apple designed the iBeacon capabilities allows one app to "listen" for only 20 iBeacons at a time. This is a problem because it limits how much a single device can be used in an iBeacon system that has more than 20 beacons. If a device reaches its maximum capacity for the number of iBeacons it can pick up, the user may miss important information from another iBeacon (S. Schmidt, personal communication, April 17, 2015).

In summary, there are a number of factors that must be taken into consideration when setting up a system of iBeacons. First, certain common materials can negatively affect the Bluetooth signals used by the beacons. It is also paramount to ensure that all beacons are working consistently and that the information they convey is up-to-date and accurate. Finally, the imposed limit on the number of beacons an Apple device (iPhone, iPad, etc.) can communicate with at one time could limit the functionality of the system for owners of those devices.

Finding #4: Bluetooth has a number of security issues that may pose problems for implementing iBeacons.

During our research of Bluetooth technology, we came across a number of reports that listed concerns about weaknesses in the Bluetooth software. Currently, a system of beacons works with Bluetooth's profile to manage its information. A Bluetooth profile typically consists of three different types of information: Device Address, Device Class, and Device Name. The Device Name is simply what the particular unit is called, specified by the device's owner. The Device Class is a descriptor of what kind of unit the hardware is (e.g. iPhone, iBeacon, etc.). Finally, the Device Address is a unique identification number (Dunning, 2010). Currently, an iBeacon app will use the Device Address to access a specific piece of information inside the app's Content Management System (CMS) via wireless internet. The CMS is an online database containing information for each individual beacon. This way, the beacon does not need to transmit any information other than its specific name, the fact that it is a beacon, and its unique identification number.

An implementation of iBeacons that function using only Bluetooth leaves the beacon system on the side of the user vulnerable to a number of malicious attacks on their Bluetooth enabled devices. One simple example is known as "spoofing." Spoofing a Bluetooth profile is simply modifying a Bluetooth Adapter so that its profile claims to be that of another device. This can be done manually, or by using one of several existing programs that can automate the process (Dunning, 2010). The most concerning aspect here regarding the implementation of a beacon system is the ability of anyone to pretend to be a beacon. If a blind person relying on the beacon system for information connects to a fake beacon, there is the chance of them falling victim to following manipulative information which may result in injury or other unfortunate outcomes.

Other concerning attacks include methods such as Bluesnarfing, Bluejacking, Bluebugging, and Denial of Service Attacks. Bluesnarfing exploits a flaw in older devices and forces a connection between devices, allowing an external device to access data stored on the victim's device (Scarfone, 2008). This is mainly a privacy issue for the user. Bluejacking is similar to spam and phishing attacks used to attack via email. Initiated by a message to a user, the message itself does not cause harm, but is used to convince the user to respond or add a new contact to their contact list (Scarfone, 2008). This method is used to further expose the victim to harm with other forms of manipulation. Bluebugging is another method that assaults older Bluetooth devices in order to exploit firmware security flaws. The ultimate danger of this type of attack is that the attacker will be able to issue commands to the victim's device without informing the device's user. This means that the attacker would be able to access information on the device, place phone calls, listen to the calls being made, send text messages, or utilize anything else the device can use (Scarfone, 2008). The danger to a blind person in this case is that their entire reliance on their device has been hijacked by the attacker. This means that whatever significance the user puts into the device is now susceptible to the whims of the hijacker. Bluetooth is also vulnerable to a more general type of attack, Denial of Service (DoS). A DoS attack is intended to make the target unusable by the intended user, rather, to deny the user the service they are attempting to use. This type of attack can drain the device's battery while making it unusable (Scarfone, 2008). If an individual is relying on the device that has been attacked this can result in a dangerous situation for them. These, as well as other Bluetooth security issues, pose a serious concern about using Bluetooth enabled devices as assistive technologies for blind people.

Finding #5: Using iBeacons strictly with Bluetooth as a proximity-based information distribution system presents a number of problems that could be solved by blending technologies.

Our visit to IBOS on April 17th brought to light a significant number of problems that arise when iBeacons are used as a proximity-based system. Currently, the beacon relays its message to the user once the user has entered the beacon's Bluetooth range. A significant problem observed was that the notification only remains active on the user's screen for a few seconds. If the user is unable to react in time or misses the message completely, there is no simple way to repeat the message immediately and on demand, and no setting that can be changed to adjust the amount of time the notification remains active. This is especially problematic in loud environments, where ambient sounds may disrupt the audible notifications or messages from the user's smartphone.

We also observed that if the user remains within range of a beacon for more than about a minute, the beacon will send the message again. The repetitive messages proved to be extremely bothersome; we were in a meeting room having a conversation with IBOS representatives and were notified approximately once per minute that we were near the meeting room. Even if the notification is acknowledged, it continues to reappear as long as the user is still within the beacon's range. The problem with the notifications is that the user has no control over if or when they repeat. It is not convenient to have to stand and wait for the next notification, and it is an annoyance to have constant repeating notifications during a meal or a meeting.

When using the proximity-based method, the Estimote iBeacons we tested have a limited number of settings for their broadcast signal strength (e.g. Low, Medium, High). Because this makes it difficult to fine-tune the coverage area of each beacon, it is possible for one user to be in the range of more than one iBeacon at the same time, which results in conflicting information. For example, at IBOS, we walked to the end of a hall and received two notifications within seconds of each other: one that we were standing outside of a restroom and one that we were standing outside of the cafeteria (on the floor above us). Receiving messages like this would be disorienting for a blind person, especially in an unfamiliar environment. Figure 7 below depicts the combination of the two problems: being within range of more than one iBeacon and receiving repeated notifications.

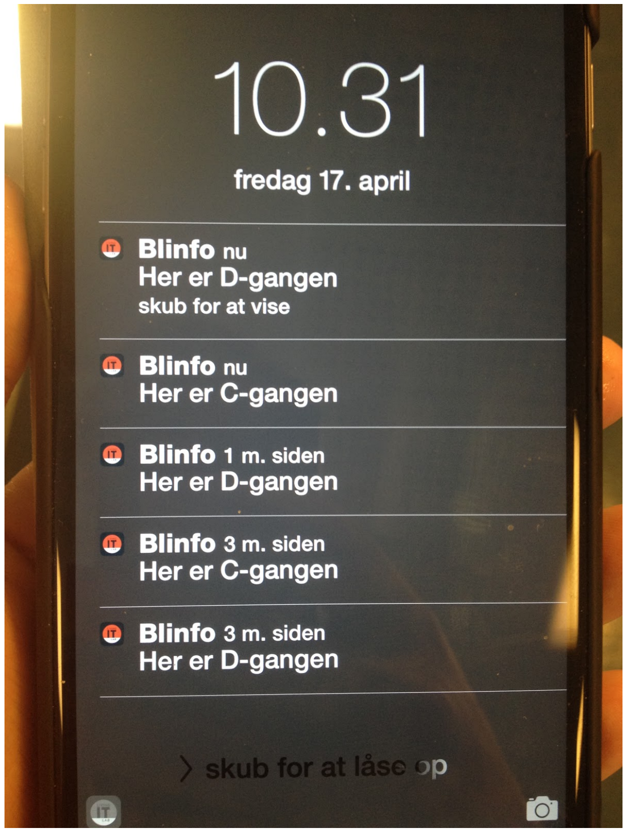

Figure 7: Photo of a smartphone screen with repeated notifications from two iBeacons during testing

The notifications in this image are telling us that we are in two different locations. In reality, we had been standing in the same corner for about three minutes, receiving notifications from two beacons.

The rest of the tests at IBOS that day had to be canceled during the first participant's trial because of the unforeseen issues mentioned above. Instead of observing trials, we instead spent the day running tests on the iBeacons with our own smartphones and learning more about the issues that were discovered. While this was not the outcome anyone was hoping for, it provided us with a learning opportunity and a chance to identify problems that need to be addressed to improve the proposed iBeacon system. While the main focus of the test was to determine if iBeacons could function as an assistive device for blind people, the Living IT Lab also wanted to test how easy it would be for an iBeacon beginner to set up a system.

Finding #6: iBeacons have been successfully implemented for navigational purposes outside Denmark.

As the DAB employees we interviewed stated, blind people are simply unable to gather certain information from their surroundings without depending on help from a sighted person. This makes traveling, especially in crowded areas like airports or train stations, a challenge for blind people. Our research has identified two organizations that have used iBeacons to make traveling independently easier for those without vision: The Royal London Society for Blind People (RLSB), located in England, and LightHouse for the Blind and Visually Impaired, located in California.

The RLSB has equipped a number of London Underground stations with Estimote iBeacons - the same ones that the Living IT Lab has been working with (Stinson 2015). Using triangulation to pinpoint the location of users' smartphones, the beacons can guide blind travelers from the station entrance to the correct platform, as well as from the platform to the station exit when they reach their destination. Currently, the system is only installed at a small number of stations on a trial basis. During a trial for RLSB, Kevin, a blind volunteer, tested the beacons at a station he had never visited before. His impression of the system was positive; he stated that the beacons made him feel "independent" and "empowered," even in the new environment. He also mentioned that the information presented by the beacons was appropriate and timed well enough that he felt as if he had a sighted guide walking with him (How Wayfindr guided, 2015). In fact, most of the blind people who tested the system thought that it was extremely useful, but that they would only need to make use of the beacons the first five to ten times they visited a new Underground station to become familiar with the layout. After that, they said, they would probably be able to navigate on their own without the app or any help from a sighted guide (Stinson 2015). This trial installation by RLSB proves that iBeacons can provide an opportunity for a higher level of independence for blind individuals.

LightHouse for the Blind and Visually Impaired, a California-based organization, has equipped Terminal 2 of the San Francisco International Airport (SFO) with hundreds of beacons from an Austrian company called Indoo.rs. By pairing the beacons with a smartphone app developed by the same company, visually impaired passengers can navigate through the terminal without an escort. The app alerts users of points of interest nearby - gates, restaurants, restrooms, even power outlets. It is even possible for a user to point his or her phone down a corridor and be provided with a list of things that can be found in that corridor. This is an example of the app working passively, but it can also work actively, guiding the user to a specified destination (Iozzio 2014). In the future, the goal is that a passenger (either sighted or visually impaired) will be able to simply input his or her airline and flight number upon arrival at the airport and be guided to the correct check-in desk, through the security checkpoint, and to the proper gate, as well as receiving updates about any flight delays or cancellations. The system uses triangulation, Bluetooth and a known Wi-Fi network as well as the compass and motion sensors built into smartphones to pinpoint a user's location to within one meter. The app provides only the relevant information for that particular location, nothing more, nothing less. It was designed from the start with input from blind people, so the app's features are aligned well with the needs of the target users (B. Bashin, personal communication, April 20, 2015). This level of input starting at the very beginning, according to Mr. Bashin, is indispensable in creating a truly accessible application.

A large part of the reason that Lighthouse and the RLSB were able to avoid the problems mentioned above is because they utilized other technologies, such as Wi-Fi, in addition to Bluetooth. Using these technologies collectively has helped them address many of the problems that using Bluetooth alone presents, and has added much more functionality to the iBeacons they use. For example, networking the beacons together with multiple technologies allows for the possibility of developing a central monitoring system. A system like this could be used to alert administrators when a beacon's battery is running low, meaning less time spent checking each individual beacon's battery level.

Combining different technologies, or as John Worsfold from RNIB called it, fusion blending, enables the system of iBeacons to benefit from each one's strengths and simultaneously minimize the negative effects caused by each one's weaknesses, such as Bluetooth's security issues (personal communication, April 21, 2015). Creating a network of beacons connected in multiple ways makes it much more difficult for a hacker to infiltrate a single beacon and take advantage of the vulnerabilities. Using a network of iBeacons also allows the system to pinpoint users' locations using triangulation, which is more accurate than using only Bluetooth. A more accurate representation of the user's location means that the user will receive more relevant information about his or her surroundings, allowing for more independence. The issue of overlapping coverage zones is also solved by a network of beacons using triangulation. The beacons work together to determine the user's location, instead of working independently as zone specific information providers. The application Indoo.rs has designed handles the beacons intelligently, so Apple's imposed 20 beacon limit never becomes a concern (B. Bashin, personal communication, April 23, 2015).

While the fact that Bluetooth signals are impeded by metal and water was initially concerning, further research determined that RLSB and Lighthouse have worked around these limitations in their implementations. Both organizations have found that strategic placement of beacons is key to avoid complications. In both instances, the beacons were placed at least three meters from the floor, or sometimes on the ceiling - above the heads of the crowd. This minimizes the interference from people in the area and allows for a larger area of coverage (J. Worsfold, personal communication, April 21, 2015). Lighthouse actually used the fact that metal impedes the iBeacons' signals to their advantage at SFO. Bryan Bashin noted that the installation used a "line of sight" approach, meaning that a user's phone will only connect to beacons it can "see" directly, not beacons that are, for example, around a corner and shielded by the metal structure (personal communication, April 20, 2015). While we were originally under the impression that this possibility for interference was a major problem, it has become clear that it is possible to avoid the issues and create an effective system.

While there are still a number of unresolved issues in the system we tested, the two implementations in London and in San Francisco demonstrate that iBeacons are capable of being a navigational tool for blind people. Their use can give users a sense of independence that other assistive tools are unable to provide. The following chapter contains a collection of the recommendations we are making for DAB as they pursue iBeacons further as an assistive technology.

Chapter 5: Recommendations and Conclusion

Based on our research and findings, we have put together a set of recommendations for the Danish Association of the Blind regarding iBeacon technology as it is currently being used by the Living IT Lab. We first want to strongly encourage DAB and the Living IT Lab to **continue pursuing iBeacons** as they possess a great deal of potential to assist the blind as an indoor navigation system. These suggestions were made in order to help these two organizations work together to create an ideal iBeacon system that can best accomplish the goals it was designed for as an indoor navigation system, particularly for blind people. The main idea of these recommendations is to address that there are significant improvements that need to be made to the current system before it can be used in the intended way.

We recommend that the Living IT Lab **continues to develop the Content Management System (CMS)** as we found the process to be highly efficient. Using one CMS would require users to download a single application, which could then be used with hundreds of beacons across Denmark. If interested groups purchase space on the CMS, their beacons could be accessed by the central app and would be used by everyone who has downloaded the app. This would prevent blind people from having to download a new app for each place they want to use iBeacons.

Additionally, our research showed that more **development needs to be dedicated to the issues of the battery life** of the beacons. Currently, someone has to check each iBeacon individually to find out how much battery life remains. There needs to be an efficient way to check the amount of energy available for each beacon in the system. Parallel to this, we suggest that there should be a simple way to determine if a beacon is working properly. Ideally, this would be accomplished in a manner allowing for checks across the entire system of beacons rather than manually checking each beacon individually.

After speaking with Bryan Bashin of LightHouse and John Worsfold from RNIB, we recommend that the Living IT Lab not use strictly Bluetooth for their iBeacon app but instead **incorporate other technologies alongside Bluetooth**, such as Wi-Fi and RFID. Using Bluetooth alone presents a number of problems with performance and security, as Bluetooth technology comes with several significant drawbacks. John Worsfold of RNIB said "I know Bluetooth alone will not satisfy [as an indoor navigation system]." He also knows from experience that "blending" multiple technologies will help iBeacons take advantage of the strengths of each one while simultaneously accounting for their respective weaknesses. Doing this will also increase the iBeacons' consistency, reliability, and functionality, and allow for more effective triangulation, enabling them to function in a similar way to GPS and to be used for turn-by-turn navigation within large and complicated indoor spaces.

Furthermore, we recommend that DAB and the Living IT Lab **get in contact with LightHouse and Indoo.rs**, the two companies who worked together to successfully implement an iBeacon network at San Francisco International Airport. In implementing these beacons, the two organizations overcame many of the problems that DAB and the Living IT Lab are struggling with. Specifically, LightHouse will be able to share what they found about helpful features the app should have. Bryan Bashin suggested that blind people should work with the programmers to create a user interface that is easily accessible by blind people. He noted that blind people do not want too much extraneous information, but also do not want too little information. They "only need, what they need, when they need it" (B. Bashin, personal communication, April 20, 2015). Then, Indoo.rs can give advice for iBeacon implementation and programming, because they have successfully blended Bluetooth, Wi-Fi, compass, and motion sensors. Based on what we have discovered and worked with, it would be highly beneficial to consult these companies to get useful information on how to improve the current system being tested in Copenhagen.

Once DAB and the Living IT Lab have overcome the challenges above and start to help companies use iBeacons to make their facilities more accessible, we recommend that they **create a guide to enable easy setup of iBeacon networks**. The guide should highlight details on where to put iBeacons relative to each other and the recommended signal strength of each iBeacon, since these two factors can have a significant impact on the effectiveness of the system. It should also point out any other details (i.e. maintenance details) that the people setting up may need to know in order to help them construct an iBeacon network that is as effective and maintainable as possible. In addition, it should include technical specifications about the iBeacons and the app to help the owners of the system understand how it should work. Examples include how to access technical information for each iBeacon, and how users should set their devices up to be able to utilize iBeacons. This information is important to include in an instruction manual in order for the owners to optimally set up the system and for the users to best take advantage of iBeacon technology.

If the Danish Association for the Blind and the Living IT Lab are able to overcome the challenges presented above and implement iBeacons as an indoor navigation system, we recommend that they also consider implementing iBeacons outdoors. After interviewing some employees at DAB, we determined that iBeacons would benefit blind people if they were placed at intersections. This could be as simple as telling the user which streets are at the intersection so that blind users can orient themselves. As technology advances, it could tell the user what stores are down whatever street the user is facing, much like the system at the San Francisco Airport.

Our research and testing has shown that iBeacon technology has great potential to help persons in the blind community. We also found several issues with how the Living IT Lab is currently using the beacons. The combination of problems with Bluetooth signal distortion, battery life, and security concerns indicates a need for intense modifications to the current implementation of beacon systems. Additionally, we found examples of successful beacon systems and suggest that the Danish Association of the Blind and the Living IT Lab make an effort to collaborate with the groups behind the systems in order to expedite the development process. Our time spent working with the blind community in Denmark impressed upon us the idea that blind people are constantly striving to be more independent in their daily lives. iBeacons could be the assistive tool that allows this dream to become a reality.

References

Adamczyk, A. (2015, January 18). "Be My Eyes" iPhone App Helps Blind People "See" Retrieved January 30, 2015, from http://www.bustle.com/articles/59301-be-my-eyes-iphone-app-helps-blind-people-see-everything-about-it-is-amazing

Binsabbar, M., & Zhang, N. (2014). An iPhone Application for Providing iBeacon-based Services to Students.

Carter, Daniel L., Janet M. Barlow, and Billie Louise Bentzen. 2007. *Accessible Pedestrian Signals: A Guide to Best Practices.* National Cooperative Highway Research Program, Transportation Research Board of the National Academies.

Captech. [Captech Ventures, Inc]. (2014, March 3). CapTech Webinar: iBeacon Demystified. Retrieved from: https://www.youtube.com/watch?v=0IGeQqEGhx4

Danish Association of the Blind (Home Page) Hovedmenu. (2012, June 26). Retrieved January 26, 2015, from <http://www.dkblind.dk/>

Dragon Speech Recognition Software. (n.d.). Retrieved January 30, 2015, from http://www.nuance.com/dragon/index.htm

Dunning, JP. [DEFCONConference]. (2013, November 7). *Breaking Bluetooth by Being Bored.* Retrieved from https://youtu.be/Nn3K8Ma_U5I

Edison, Tommy. [TommyEdisonXP]. (2014, April 1). *How Blind People Use A White Cane.* Retrieved from https://www.youtube.com/watch?v=HoeUyyCpStA

Elgan, M. (2013, September 14). Why Apple's 'indoor GPS' Plan is Brilliant. Retrieved January 30, 2015, from http://www.computerworld.com.au/article/526543/why_apple_indoor_gps_plan_brilliant/

GPS Technology for the Blind, a Product Evaluation. (2006, February 1). Retrieved February 7, 2015, from <http://www.nfb.org/Images/nfb/Publications/bm/bm06/bm0602/bm060206.htm>

Guide dogs compared to canes. (2012, January 12). Retrieved February 7, 2015, from http://www.mdjunction.com/forums/retinitis-pigmentosa-discussions/general-support/3373859-guide-dogs-compared-to-canes

Hager, C. T., & Midkiff, S. F. (2003, March). An analysis of Bluetooth security vulnerabilities. In *Wireless Communications and Networking, 2003. WCNC 2003. 2003 IEEE* (Vol. 3, pp. 1825-1831). IEEE.

How Wayfindr guided my first steps to independence on the tube. (2015, March 6). Retrieved March 23, 2015 from http://www.rlsb.org.uk/blogs/how-wayfindr-guided-my-first-steps-to-independence-on-the-tube

Hughes, T. (2013, June 10). Shock at record attacks on guide dogs. Retrieved February 26, 2015, from http://www.express.co.uk/news/uk/406348/Shock-at-record-attacks-on-guide-dogs#

Iozzio, C. (2014, August 8). Indoor Mapping Lets the Blind Navigate Airports. Retrieved March 24, 2015 from http://www.smithsonianmag.com/innovation/indoor-mapping-lets-blind-navigate-airports-180952292/?no-ist

Jacobsen, H. (2013, August 10). Workplace prejudice keeps blind people out of employment. Retrieved February 26, 2015, from http://www.euractiv.com/files/styles/x-large/public/gallery/blind-person-with-cane.JPG?itok=OjGJ56us

Partially sighted. (n.d.) *iMedix patient discussion forum*. (2010). Retrieved January 30 2015 from http://medical-dictionary.thefreedictionary.com/Partially+sighted

Pascolini D, Mariotti SPM. Global estimates of visual impairment: 2010. British Journal Ophthalmology Online First published December 1, 2011 as 10.1136/bjophthalmol-2011-300539.

Politzer, T. (n.d.). Introduction to Vision and Brain Injury. Retrieved February 19, 2015, from https://nora.cc/vision-a-brain-injury-mainmenu-64.html

Scarfone, K., & Padgette, J. (2008). Guide to bluetooth security. *NIST Special Publication*, *800*, 121.
http://www.mcs.csueastbay.edu/~lertaul/BluetoothSECV1.pdf

Schmidt, Stefan. “Beacons i social IT-løsninger.” Report. Living IT Lab, 2015.

Stinson, L. (2015, March 18). Guiding the Blind Through London's Subway With Estimote Beacons. Retrieved March 23, 2015 from http://www.wired.com/2015/03/blind-will-soon-navigate-london-tube-beacons/

United Nations Convention on the Rights of People with Disabilities database. (n.d.). Retrieved March 25, 2015, from http://www.euroblind.org/convention/nr/66

Vejdirektoratet. (2006, July). Signaler: Lydsignaler for blinde og svagsynede. Vejdirektoratet

Watt, W. (2003, October 6). How Visual Acuity is Measured. Retrieved January 30, 2015, from http://lowvision.preventblindness.org/eye-conditions/how-visual-acuity-is-measured

What is iBeacon? A Guide to iBeacons. (n.d.). Retrieved January 24, 2015, from http://www.ibeacon.com/what-is-ibeacon-a-guide-to-beacons/

Whitmarsh, L. (2005). The benefits of guide dog ownership. *Visual impairment research*, *7*(1), 27-42.

Appendices

Appendix A

Questions for Jack Cox

1. How long have you been working with iBeacons?
2. What are the pros/cons of using iBeacon CMS (Content Management System on the Web)?
3. What are the pros/cons of using iBeacon mobile Apps?
    a. Missing some features?
4. What areas are hardest to setup/test?
5. Do iBeacons themselves have a “lifespan” (outside of the battery), meaning is there a certain amount of time before it would need to be replaced?
6. What privacy/security issues/concerns, if any, have you taken into account? How has your team addressed the security concerns of Bluetooth technology?
7. Is there a way to have a universal mobile app to be used rather than many apps for different locations/companies?
8. Can you think of any ways iBeacons could help blind individuals?

Appendix B

Questions for Mark Badger

1. How long have you been working with iBeacons?
2. Focusing on the user interface, what are the pros/cons of using iBeacon CMS (Content Management System on the Web)?
3. Focusing on the user interface, what are the pros/cons of using iBeacon mobile Apps?
    a. Missing some features?
4. Does CapTech create apps for companies that want to use iBeacons?
5. How did you evaluate the different considerations for the user interface?
6. From the user's perspective, what privacy/security issues/concerns, if any, have you taken into account? How has your team addressed the security concerns of Bluetooth technology?
7. Is there a way to have a universal mobile app to be used rather than many apps for different locations/companies?
8. Has accommodation and accessibility for the blind been considered during the UI design process?
9. Can you think of any ways iBeacons could help blind individuals?

Appendix C

Questions for Stefan Schmidt and Mads Andersen

1. What difficulties have you run into when testing iBeacons?
2. Do iBeacons themselves have a "lifespan" (outside of the battery), meaning is there a certain amount of time before the device would need to be replaced?
3. Outside of replacement, how much maintenance would a single iBeacon typically require, and how often?
4. What privacy/security issues/concerns, if any, have you taken into account? How has your team addressed the security concerns of Bluetooth technology?
    a. From the User's Perspective?
    b. From the iBeacons' Perspective?
5. Is there a plan in place to start implementing iBeacons beyond the prototype stage?
6. Other organizations are testing iBeacon as well. Have you reached out to any of them?
7. Have you heard of Copenhagen's project called Smart City?

Appendix D

Interview Questions for Bryan Bashin

1. Having never been to the San Francisco Airport, we're not sure of the layout. Could you tell us approximately how much space the 300 beacons cover?
2. Does the system you installed triangulation or proximity-based information distribution?
3. How long did it take to set up the Beacons?
4. We've read that Bluetooth signals have trouble passing through both metal and water. An airport is an area with a lot of metal and a lot of people (water). Did you experience any issues with the signals, and if so, how did your team overcome it?
5. Did your team run into any other big obstacles during setup/testing?
6. What was the testing and setup process like?
7. How did blind testers feel about it?
8. The articles we've read were generally written last year. How has the project been going? Have there been any major advances or major obstacles since then?

Appendix E

Interview Questions for John Worsfold

1. Does the system you installed triangulation or proximity-based information distribution?
2. How long did it take to set up the Beacons?
3. We've read that Bluetooth signals have trouble passing through both metal and water. An airport is an area with a lot of metal and a lot of people (water). Did you experience any issues with the signals, and if so, how did your team overcome it?
4. Did your team run into any other big obstacles during setup/testing?
5. What was the testing and setup process like?
6. How did blind testers feel about it?
7. The articles we've read were generally written last year. How has the project been going? Have there been any major advances or major obstacles since then?