An Analytical Approach to Using and Implementing Beacons: Opportunities and Challenges

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Abstract

Beacon technology has great opportunities that offer a broad potential to enhance consumers' experience. In this paper, we explore the advantages, disadvantages and challenges of using and implementing beacon technology. The qualitative research materials were gathered by reviewing reliable articles, reports and applications. The number of software applications ("Apps") that are being analysed is limited to 50 applications that operate on iOS and Android platforms. The aim of the research is to provide a clear insight into beacon technology and the opportunities it offers to improve user experiences on mobile devices. The findings indicate that beacons' interaction with mobile applications (implementing beacon protocols) enhances users' experience and satisfaction by enabling indoor navigation and proximity navigation. However, there are several challenges, such as privacy, security and applications' usability that have caused users' dissatisfaction.

Keywords: Beacon, iBeacon, Eddystone, iOS, Android, Applications

1 Introduction

The fourth generation of Bluetooth 4.0, known as Bluetooth Low Energy (BLE), has been incorporated and implemented by leading companies such as Apple and Google in their mobile devices to enhance the user's experiences. Apple's iBeacon™ and Google's Eddystone™ technologies are the most used protocols for beacons. Both protocols provide a similar function, which is to broadcast information packets. iBeacon requires a license from Apple, which is a hindrance to its spread and implementation, as well as a specific app (installed in the user's device) in order to receive a specific packet. On the other side, Eddystone is an open source protocol which can increase its adaption to many beacons, and it can use web browser to receive any beacon packet (if there is no recipient application) [1].

This technology can be used for many situations, including proximity detectors, heart rate monitors, blood glucose monitors, temperature sensors, humidity sensors and health thermometers [2].

Newman [3] describes BLE beacons as cheap, small devices that emit a signal which can be picked up at close range by a smartphone (using the same technology). Therefore, smart-phones' apps entering the range of the beacon signal can trigger a specific event designed by the app developer. Also, the smartphone's ability to calculate the distance between itself and the beacon allows it to trigger specific events for each distance. Beacon devices can be developed based on any of the iBeacon™, Eddystone™ or AltBeacon™ protocols.

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The purpose of this research is to create an extensive overview of the advantages, opportunities and challenges of this new technology. We have conducted an extensive literature review assessing the impact of BLE on users. Findings of the literature review were applied in the analyses of 50 different iOS and Android applications that use BLE technology. The findings explore challenges related to beacon deployments, such as usability, privacy and security. Users' satisfaction and dissatisfaction are also observed by analysing their feedback while using beacon-enabled applications.

The literature review addresses several aspects related to the use of beacons, following by a discussion part explaining the beacon opportunities and challenges, as well as issues that arise from the literature review. Following next is an analysis of applications that were implemented using BLE beacon technology. Finally, our conclusion summarizes the main findings of this research.

2 Background

Apple Inc. [4] released the iBeacon™ protocol to enable location awareness for iPhone's applications with the launch of iOS7 software in 2014. iBeacon™ uses Bluetooth Low Energy (BLE) to create a region around an object which detects an iOS device when it enters or leaves the region and gauges its distance from the beacon. Apple's iBeacon broadcasts only advertising packets that have a unique ID number formed by Universally Unique Identifier (UUID), Major and Minor fields [4]. The advertised packet contains specific information to interact with a specific application defined by the application developer.

Google's Eddystone™ is a protocol specification that defines the Bluetooth low energy (BLE) message format for proximity beacon messages. It can be detected by iOS and Android observers and describes several different frame types that may be used individually or in combinations to create beacons that can be used for a variety of applications [5].

Google Eddystone™ broadcasts four individual frames which define the message type (Figure 1). (1) Eddystone-UID, functioning as a unique ID number like iBeacon, broadcasts an obscure, unique, beacon ID composed of 16 bytes: 10 bytes are used for the namespace to group a particular set of beacons and a 6-byte instance is used to identify individual devices in the group. (2) Eddystone-URL broadcasts a compressed, encoded URL format in order to fit easily within the limit of the advertisement packet. Therefore, any client who receives this packet will have the opportunity to choose to visit that URL. The use of Eddystone-URL frames assumes the availability of an Internet connection to retrieve resources pointed to by the broadcast URLs. (3) Eddystone-TLM broadcasts telemetry data about the beacon itself, such as battery voltage, device temperature, and counts of broadcast packets. (4) The Eddystone-EID frame broadcasts an encrypted ephemeral identifier which changes periodically to be used in security and privacy-enhanced devices [1, 5, 6].

AltBeacon™ is a protocol specification that defines a message format for proximity beacon advertisements which Bluetooth Low Energy proximity beacons broadcast. It was launched for the first time in 2014 by Radius Network to be an open and interoperable specification for proximity beacons [7].

It must be stated that, although the three protocols have similar characteristics, a company wishing to use the iBeacon™ protocol must have a license from Apple [4]. A license is not required for using the Eddystone protocol, which is Open Source.

2.1 Applications

Beacons have brought several opportunities to application developers and customers. Beacons can enhance an indoor positioning system and indoor navigation. Dalkılıç et al. [8] stated that GPS satellites

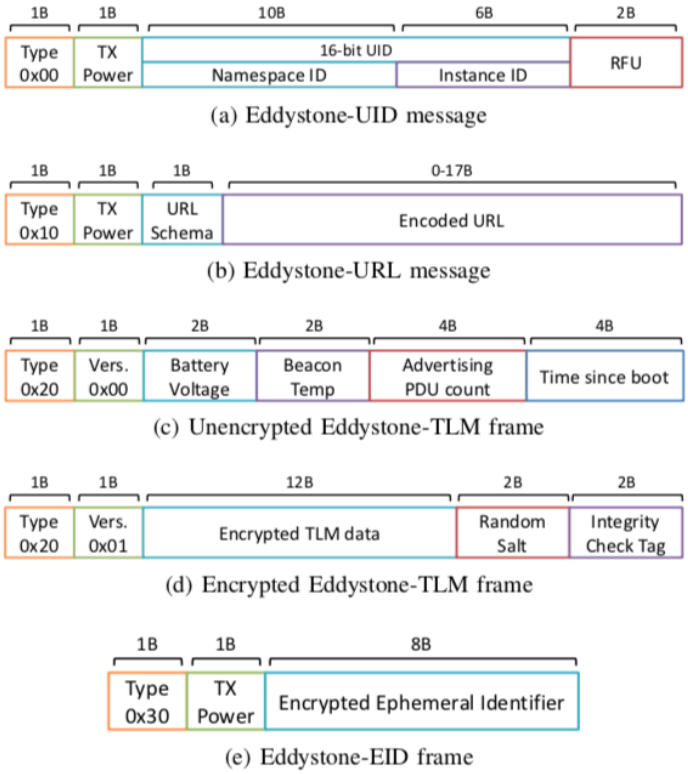

Figure 1: Format of Eddystone messages [6]

are mature positioning systems, but GPS does not function reliably in an indoor environment. However, iBeacon is a new technology that can be used to enhance the indoor positioning experience. It can be relied on as an indoor positioning system where location accuracy is not a rigorous requirement. Yang et al. [9] also indicated that iBeacon can be used for indoor positioning systems and indoor direction-finding in hospitals to aid patients while navigating their way.

Uttarwar et al. [10] also discuss the use of beacon technology to enable indoor navigation. With this type of beacon application, indoor navigation can be achieved and can be used in airports, offices, retail areas and hospitals. It can also provide information on the location and number of visitors at a specific time of day. The authors propose a Beacon Enabled Smart Library System that utilizes an Android application (BeaLib) for navigating a library and providing the library user with information about books. When a student enters the beacon signal range, she/he will receive notifications from an *Estimote*™ Bluetooth beacon that holds information about specific books.

Another example of beacons used in providing guidance to people in indoor places is the Australian Museum's (AM) mobile app, designed to enhance visitors' experience and provide information about current and upcoming exhibitions and events. Conversely, it also enables museum staff to identify popular and unpopular exhibits by using the position logging of museum visitors. The monitoring function, which detects entering and exiting can report user acceptance according to a visitor's decision to check the information, interact with the artwork or do nothing [11].

Beacons can also be used for tracking purposes. Baek et al. [12] argue that beacons are suitable to check truck travel times in open-pit mines, due to their wide-ranging coverage and ability to be recognized by sensor devices. Alapetite and Hansen [13] provide an Internet of Things (IoT) platform for sight- or physically- impaired users to discover nearby items, get their status, and interact with them by

(for example, using voice commands or gaze gestures). To make this possible, they added the concept of dynamic payloads and actuation to normal beacons.

Park et al. [14] provide an idea for a Smart Factory that uses a combination of BLE and Wi-Fi to let the management make the best decisions by collecting on-site 4M1E (Man, Machine, Material, Method, and Energy) data in real time. The proposed system tracks all entities inside the factory and prompts the management in case of an accident by determining the exact position.

2.2 Security and Privacy

Tay et al. [15] describe three types of beacon vulnerabilities: spoofing, denial of service and hijacking. Spoofing is the most common vulnerability because the iBeacon protocol broadcasts its UUID publicly. Therefore, any third-party 'sniffing' tools can capture a specific beacon's UUID, which will enable it to impersonate that beacon anywhere. Gast [16] indicates that the main security issue for the iBeacon protocol is the complete absence of cryptographic security. This enables spoofing because the contents of the beacon frame are neither authenticated nor encrypted. Therefore, a hacker can learn the iBeacon numeric identifier easily and use it in his/her beacon for piracy. Spoofing also can be used to abuse a loyalty rewards program to misdirect users, to spam the user device, to gain the attacker unauthorized access to the device, and to cause inaccurate behaviour of the application.

Denial of Service DDoS attacks can be used to drain the battery of the beacon or to damage the Bluetooth stack. An attacker can disconnect the user from the services provided by an application, which will lead to user dissatisfaction.

Hijacking vulnerabilities may enable unauthorized third-parties to access the configuration layer of the iBeacon, giving the attacker control to change the iBeacon's operational settings. This will allow the attacker to manipulate data and swap locations to misdirect users or lock them out of the application.

These vulnerabilities can affect the efficiency of beacons (targeted notifications, tracking/metrics, navigation and authentication), so some companies that used the iBeacon protocol implemented their own defences against it. For example, the *Gimbal*™ beacon provides a private mode and rotating UUID to overcome spoofing attacks and uses time-limited session configurations to overcome DDoS and hijacking attacks [15].

An iBeacon can be used for tracking purposes in combination with smartphone applications (such as a fitness app). This enables the application to use the beacon to track data and send it or upload it to its cloud server for further analysis [16]. Also, using beacons in retail stores leads to business advantages by analysing customer habits to allow targeted messages in the future.

Even though some authors state [16] that there is no privacy issue with the iBeacon because it only sends a signal and it cannot receive any signal from other mobile devices, customers have concerns about their privacy [3]. Another challenge for this technology is devices' battery life (battery drain by keeping the Bluetooth on all the time and leaving the app running in the background) [3].

2.3 Accuracy

According to Apple Inc [4], the proximity estimations of iBeacon employ a ranging process calculation which depends on the signal strength of the beacon to determine its distance from a device (smartphone).The range is categorized into four statuses: Immediate (the device is very close to the beacon), Near (the device is 1-3 meters from the beacon), Far (the device is merely indicated by the beacon) and Unknown (the proximity of the beacon can't be determined).

Dalkılıç et al. [8] have developed an application that receives iBeacon signals, and used three *Estimote*™ proximity beacon devices to determine the user's location and proximity accuracy. In the first scenario, the three *Estimote*™ beacons were placed in three locations, located two meters away from the

receiver (”the phone”), so that the signal could be affected by wall and signal interference. In the second scenario, one *Estimote*™ beacon was placed at different distances, ranging from one meter to eight meters from the receiver. The result showed that proximity accuracy could be affected by the receiver itself (“the phone signal”) but, generally, the further the beacon was from the receiver, the more accurate the distance reading was. The final scenario used three *Estimote*™ beacons in one room and a laptop computer located in another room, so the accuracy of the receiver was affected by the signal interference of each beacon, the laptop, and the receiver. Based on this research, the researchers have concluded that the iBeacon can be considered reliable for indoor positioning system where location accuracy is not a rigorous requirement, but iBeacon signals are affected by obstacles like walls, people, and other devices [8].

Čabarkapa et al. [17] compared and analysed Bluetooth Low Energy (BLE) Indoor Positioning System (IPS) positioning techniques. The trilateration technique uses a trigonometric position estimation algorithm by measuring three known reference points (beacon nodes). This technique relies on using the Received Signal Strength Indicator (RSSI) to determine the distance of the device from a beacon. The “fingerprinting” technique manually registers RSSI reference points for specific indoor positions to create a radio map. Then it compares the mobile user’s estimated RSSI location to the registered RSSI reference to determine the accurate location of the user. The authors concluded that the fingerprinting technique is more accurate than the trilateration technique because the radio frequency of the beacon in trilateration technique is affected by indoor obstacles, such as people and furniture.

Other authors [12] compared the performance of Bluetooth Low Energy BLE and reverse Radio-Frequency Identification RFID in measuring track travel time. This research used beacons and RFID tags around a university campus as checkpoints and used a smart-phone to scan beacon signals and RFID radar to scan RFID tags. The authors recorded video while driving around the campus to record the actual time when they passed the checkpoints. Comparing the actual time with the smartphone and RFID reader logs, showed that the beacon scored an average of 98% sensor recognition with an average of 1.1% timing error, whereas RFID scored an average of 61% sensor recognition with an average of 0.80% timing error.

The literature indicates that beacons can provide unique methods of interaction with applications on iOS and Android platforms. Also, it shows that beacons’ indoor navigation, proximity triggered action, and management features provide new users’ experience which enhance their engagement with the physical world. These features can form main three categories for implanting beacons in applications. The review also identified security and privacy as challenges that may limit the adoption and implantation of beacon technology in application development.

3 Applications Analysis and Review

The application analysis covers applications that operate on mobile operating system platforms on handheld devices such as smart-phones, tablets, smartwatches and others. It focuses on the dominant mobile OS’s: Apple’s iOS and Google’s Android. According to [18], Apple’s iOS has a market share of 15% in smartphone OS’s whereas Google’s Android has 80% in the same market. According to [19], Apple’s App Store™ has 2.2 million iOS apps, whereas the Google Play™ store has 2.8 million Android apps.

3.1 Method of searching applications

The searching method for beacon applications on Apple’s App Store™ included the keywords beacon, ibeacon, Eddystone, and AltBeacon in the AppApp™ search engine. AppApp™ is a third-party search

engine dedicated to searching iOS applications. The results of the search are shown in Table 1.

Keyword	Found app results	App categories
beacon	1761	449 in lifestyle
		288 utilities
		249 in entertainment
iBeacon	965	241 in lifestyle
		226 utilities
		199 in entertainment
Eddystone	27	8 in business
		17 utilities
		8 in productivity
AltBeacon	3	1 in business
		2 utilities
		1 in education

Table 1: Results of iOS applications found

The searching method for Google's Play™ store beacon applications included the keywords beacon, ibeacon, Eddystone, and AltBeacon in the Play Store search engine. The search results are shown in Table 2.

Keyword	Founded app result	App Categories
beacon	350	Unavailable
iBeacon	250	Unavailable
Eddystone	350	Unavailable
AltBeacon	85	Unavailable

Table 2: Results of Android applications found

The results (Table 1, Table 2) show that out of 1592 applications, 1,215 applications use iBeacon™ protocol and 377 applications use the Eddystone™ protocol. By focusing on applications that work on both platforms, the number was reduced from 1592 to 600 applications. After reviewing the applications' name, description and intended functionality, 50 applications that had a clear description mentioning the implementation and use of beacon protocols within the application were chosen for further analysis. Based on the application's functionality (describing the intended integration of beacons such as indoor navigation, proximity and management), 26 applications that had the clearest description and functionality were selected for the final analysis.

The applications review was based only on the comments of the users of Android platforms from Google's Play™ store because these were transparent and easily accessible from desktop browsers. On the other hand, Apple's App Store™ users' reviews were limited to three random reviews for each application when accessed from desktop browsers. Thus, the review analyses were not conducted for iOS applications.

Some applications did not have sufficient popularity because their use was confined to a particular place and for a specific purpose, such as Mima Beacon™ which was downloaded slightly more than 50 times with only one review. Other apps, such as *AudemarsPiguet, Enso Locate, Kid Tracker, BeHere, Social Retail Mobile to Mobile, and JAL BLE Beacon Locator* did not have any review. Moreover, some applications were listed in Google Play™ when we searched for the applications, but actually had been removed by the developer and could not be used anymore (for example, this was the case with *You parked*

here™), and we couldn't obtain users' feedback about those applications. These applications are noted with "No review available" in Table 3.

3.2 Application analysis

We analysed applications' description, features, and functions in order to classify each app's features into three main categories and several subcategories. This classification was based on types of application usage identified in the literature review (indoor location and proximity, proximity-trigged action, and management). Table 4 summarises applications' main usage and features. Further description of each application is provided in section 3.3.

3.2.1 Category 1- Indoor location and proximity

The indoor location and proximity category covers apps that use beacons to replace GPS usage inside a building and enhance indoor navigation and positioning. This category has six subcategories.

1. The first subcategory comprises applications that offer a map replacement feature to provide clear directions within large buildings, such as hospitals and malls.

2. Applications that offer transit assistance and information for users in airports, train stations and any places that act as a hub for travellers, to help them to find the needed gate or another point of interest, are in the second subcategory.

3. The third subcategory consists of indoor navigation and positioning features which work in combination with the previous subcategory to provide direction in megacities. For example, the Sydney airport application provides an indoor map to help users at the airport to find service offices and stores locations. Also, it provides real information about the user's flight gate and it can assist him/her toward the departure gate. Moreover, the application shows the location of trains and taxis on the map to help the user to travel easily.

4. The fourth subcategory covers applications that provide guidance information for users in places such as museums. For example, the *Australian Museum* Application helps the users to explore and navigate the Museum in an interactive way, enabling the user to take a self-guided audio tour through the exhibitions and permanent galleries. Also, it helps the users to discover the stories behind an object or specimen on display.

5. The fifth subcategory includes applications that can enhance a store or other venue based on the user's experience during his/her visit. For example, unlike the previous applications, the Trailblazers Exhibition provides an app called *"Trailblazers"* which allows its users to play an activity called "Find and Collect," involving items inside the exhibit, by picking a character and using the 'radar' and clues to find all the items.

6. The final subcategory covers applications that provide tracking features for the user's objects. *TAG IT*™, which has been installed more than 50,000 times by Android phone users, is a great example of this subcategory. It provides tracking and locating functions for objects tagged with beacons within 75 feet by launching an alarm sound for the tagged objects.

Application	Number of reviewers	Number of installs	Overall Rate out of 5 stars	Percentage of rating					Positive reviews				Negative Reviews			
				1	2	3	4	5	Usefulness	Ease	Helpfulness	Internet needless	Crashes issues	Subscription fees	Sign up/Login issues	Maps failures
Australian Museum	23	1000+	3.5	0	0	17	17	65	-	-	-	-	✓	-	-	✓
Trailblazers	4	500+	3.2	25	25	0	0	50	✓	-	✓	-	-	-	-	-
Sydney Airport	297	50000+	3.6	18	8	11	20	43	✓	✓	✓	-	✓	-	-	-
Audemars Piguet	No review available															
MCG	13	1000+	4.2	0	0	31	23	46	✓	X	✓	-	✓	-	✓	✓
Enso Locate	No review available															
Kid Tracker	No review available															
Leash It	23	1000+	2.4	57	9	4.4	0	30	✓	✓	-	-	-	-	-	✓
BeHere	No review available															
Social Retail Mobile to Mobile	No review available															
Hailo	37800	1,000,000+	4.7	2.9	1	2.2	12	82	✓	✓	✓	-	-	-	-	-
HotSpot Parking	544	10,000+	3.7	24	4	3	15	54	✓	X	-	-	-	✓	-	-
National Aquarium	58	10,000+	3.7	17	9	6.9	17	50	✓	✓	-	-	✓	-	-	-
Coupgon	917	100,000+	3.1	27	11	15	18	29	-	-	-	-	-	-	✓	-
Prise	1345	100,000+	2.8	38	9	11	13	28	-	-	-	-	✓	-	-	✓
JAL BLE Beacon Locator	No review available															
Tag it	345	50000+	2.6	48	8	8.4	8.2	28	✓	-	✓	-	-	-	-	-
You Parked Here	The app was removed from Google Play[a] store															
R T H	22	1,000+	3.5	27	9	4.6	9.1	50	✓	-	-	-	✓	-	-	-
BlueSense	No review available															
BuddyTag for School	103	10,000+	2.8	41	11	7.8	8.7	32	-	-	✓	✓	✓	-	-	-
MLB Ballpark	5223	1000,000+	4	12	5	8.9	20	54	-	-	✓	-	✓	-	✓	-
Frankfurt Airport	1388	100,000+	3.7	17	9	7.9	19	47	X	✓	-	-	✓	-	✓	✓
Mima Beacon	1	50+	5	0	0	0	0	100	-	-	-	-	-	-	-	-
Silent Beacon	15	1,000+	3.9	27	0	0	0	73	✓	-	✓	-	-	-	-	-
Blicker Bluetooth For Students	44	5,000+	4.5	6.8	5	2.3	6.8	80	✓	✓	✓	✓	-	-	-	-

Table 3: Application Review

				Indoor Location and Proximity						Proximity Trigged action			Management		
Application	**Platform**		Category Based on app description	Map replacement	Transit assistance	Indoor navigation & positioning	information guidance	Retail store enhancement	Tracking	Mobile advertisements	Ticket validation	Power consumption	Queue measurement	Product readiness	Transaction completion
	iOS	Android													
Australian Museum	✓	✓	Ent	X	X	✓	✓	✓	X	X	X	X	X	X	X
Trailblazers	✓	✓	Games	X	X	✓	X	✓	✓	X	X	X	X	X	X
SydneyAirport	✓	✓	Travel	✓	✓	✓	X	✓	X	✓	X	X	X	X	X
Audemars Piguet	✓	✓	Lifestyle	X	X	X	X	✓	X	✓	X	X	X	X	X
MCG	✓	✓	sport	✓	✓	X	X	✓	X	✓	✓	X	✓	X	X
Enso Locate	✓	✓	Navigation	✓	X	✓	✓	X	X	X	X	X	X	X	X
Kid Tracker	✓	X	Utilities	X	X	✓	X	X	✓	X	X	X	X	X	X
Leash It	✓	✓	Social Net	✓	X	✓	✓	X	✓	X	X	X	X	X	X
BeHere	✓	✓	Education	X	X	X	X	X	✓	X	X	X	✓	X	X
Social Retail Mobile to Mobile	✓	✓	Utilities	X	X	X	X	✓	✓	✓	X	X	✓	X	X
Hailo	X	✓	Navigation	✓	✓	X	X	X	✓	✓	X	X	✓	X	✓
Hotspot Parking	✓	✓	Travel	✓	✓	✓	✓	X	X	✓	✓	X	✓	X	✓
National Aquarium	✓	✓	Travel	✓	X	✓	X	✓	X	✓	X	X	X	X	X
Coupgon	X	✓	Lifestyle	X	X	X	X	✓	✓	✓	X	X	✓	X	✓
Prise	✓	✓	Lifestyle	✓	✓	X	✓	✓	✓	✓	X	X	X	✓	X
JAL BLE Beacon Locator	✓	X	Utilities	✓	X	✓	✓	X	✓	X	X	X	X	X	X
TAG IT	✓	✓	Utilities	✓	X	✓	✓	X	✓	X	X	X	X	X	X
You Parked Here	✓	✓	Lifestyle	X	X	✓	X	X	✓	X	X	X	X	X	X
R T H	✓	✓	Weather	X	X	X	X	X	X	✓	X	X	X	X	X
BlueSense	✓	✓	Utilities	X	X	✓	X	X	✓	X	X	✓	X	X	X
BuddyTag for School	✓	✓	Utilities	X	X	✓	X	X	✓	X	X	X	✓	X	X
MLB Ballpark	✓	✓	sport	✓	✓	✓	✓	✓	X	✓	✓	X	✓	X	✓
Frankfurt Airport (FRA)	✓	✓	Travel	✓	✓	✓	✓	✓	X	✓	✓	X	X	X	✓
mima Beacon	✓	✓	Reference	X	X	✓	✓	✓	X	X	X	X	X	X	X
Silent Beacon - Personal alert	✓	✓	Lifestyle	✓	X	✓	✓	X	✓	X	X	X	X	X	X
Blicker Beacon Poll for Teacher	✓	✓	Education	X	X	X	X	X	X	X	X	X	✓	X	X

Table 4: Application Analysis

3.2.2 Category 2- Proximity-trigged action

The second main category is that of proximity-trigged action, which covers apps that have features associated with mobile devices entering or leaving the beacon signal range.

1. The first subcategory covers applications that send a mobile advertisement to the users of smart devices.

2. The second subcategory covers applications that help in validating a user's electronic tickets. such as a train or a sports match ticket. For example, the *MLB Ballpark*™ app receives mobile notifications and advertisements for its users, such as offers, rewards and exclusive content during the user visit to a Major League Baseball ballpark. The application also enables users to buy a ticket online which can be used for electronic validating

3. The third subcategory covers applications that can be used to control electrical appliances, such as turning on or off an Air Conditioner when a user enters or leaves the house/office.

3.2.3 Category 3- Management

The management category is divided into three subcategories, which covers apps that provide measurement and transaction capability.

1. The first subcategory covers applications that measure a queue of customers waiting in line for services and then notify them about the approximate waiting time.

2. The second subcategory includes applications that provide payment options and transactions by using beacon technology. For example, the *HotSpot Parking*™ app is used to notify its users about vacant parking spots in the surrounding area to save time. Also, the app includes payment options for the parking session.

3. The third subcategory covers applications that can be used to notify their customers about product readiness. For example, *Prise*™ is an application that provides its users with offers in certain restaurants, and it can notify them about waiting time to have a table in the chosen restaurant.

3.3 Application Review

Due to the lack of information on Apple's App Store™ regarding apps' number of downloads and users' reviews, this section analyses users' reviews only for Android applications on Google Play™ store. The analysis of users' reviews was based on two key points: the overall evaluation and rate of the application; and factors of acceptance or rejection of the application. The review included the following applications.

Australian Museum provides information about historic sites, upcoming events, and self-guided tours for its users. The App received an average of 3.5 out of 5 stars and the number of installations was more than 1000, with a total of 23 reviews from users. Users complained about issues in the map functionality and sudden crashes, and some commented that the app was "useless".

Trailblazers is part of the Australian Museum exhibition which enables users to play location-based games. The App received an average of 3.2 out of 5 stars and the number of app installation was more than 500 with a total of four comments from users. One user said the app made the kids involved in the museum but another one said the involvement was . . . "useless".

Sydney Airport™ offers its users information about flight schedules and the locations of airport terminals, shops, and services. The App had 297 users' reviews. 42.8% of them (around 127 users)

ranked the application with five stars as being a desirable application. They found it helpful and easy to use. The only concern with this application was "sudden stops and crashes".

MCG is the official app of the Melbourne Cricket Ground, which aims to improve users' matchday experience. The App received 4.2 out of 5 stars and the number of installations was more than 1000. There were thirteen reviews from users. Users commented that "the App keeps buffering," "is not easy to navigate" and "freezes".

Leash It enables users to track and recover stolen items based on the proximity feature. The App received 2.4 out of 5 stars and the number of installations was more than 1000, with a total of 23 comments. Most users complained about" inaccurate proximity reading". On the other hand, seven users commented that the app "worked perfectly".

Some applications, such as *Hailo*, have a massive review because of their popularity and usability. The app enables users to track a requested taxi in real time and the user can pay for the ride through the app. The app received 37,800 reviews and has been downloaded more than 1 million times, with a high grade of satisfaction among 82% of its users.

HotSpot parking enables users to pay for parking, to purchase transit passes and use proximity to receive notifications about free parking spaces. The app received 3.7 out of 5. Most reviewers agreed that "the idea is great, but had poor execution". Users complained about many issues related to "subscription fees," dealing with the "app's menu," and "usability issues" at different times.

National Aquarium offers its users guidance in the Baltimore Inner Harbor attraction, in the form of visitor tips, event information and guide maps, by using proximity features. The app was installed more than 10,000 times and 58 users rated it. They ranked it at 3.7 out of 5 stars. Most of the users complained about "frequent crashes".

Coupgon provides its users with exclusive offers when they are in-store, using the proximity feature at participating locations. This application was rated at 3.1 out of 5 by 917 users and it was installed more than 100,000 times. Around 25% of users commented that it had "limited coupon offers" and "limited participating stores". Users also reported "login/Sign up issues".

The *Prise* application is categorized as a lifestyle application which provides users with exclusive deals and offers when they are near a restaurant, using the proximity feature. The app also provides directions to the restaurant's location. It was rated by 1345 users, and 375 of them gave the application 5 out 5 stars, but the majority of users were "not satisfied". There were no reviews on the application, so there are no explanations about the type of problems they faced.

TAG IT enables users to track and find a tagged object within 75 feet, using the proximity feature. The app received 2.6 stars out of 5 and the number of installations was more than 50,000, with a total of 345 reviews. The app received 5 out 5 stars from 96 users and they were happy with the tracking feature. However, 166 users gave the app a 1/5 score because the app "did not track" their tagged item.

RTH Remote Thermo Hygrometer uses beacons to read the environmental temperature and relative humidity and send the readings in the form of a report to the app on the user's device. The App received 3.5 out of 5 stars from 22 users but there were no comments in the reviews.

BuddyTag for School enables teachers and chaperones to track their students while on a field trip using proximity. The app was installed more than 10,000 times, with 103 reviews, and received 2.8 out of 5 stars. Some users reported that the app "worked well" but the majority commented that they had "issues," such as "connecting the app to the tag," "crashing" and noted that "the proximity distance coverage and reading was limited".

MLB is the official app of Major League Baseball. Ballpark offers its users complimentary items and personalizes journal, tickets, social media, offers, rewards, and exclusive content. The App received a 4.0 star rating out of 5 and the number of installations was more than 1,000,000. The total reviews were 5,233, and 2,832 reviewers gave the app 5 stars; most of them were happy with the features that were provided, such as ticket validation and navigation around the stadium. However, 670 users gave the app

1 star due to “issues in ticket-buying” “functionality” and “account connectivity”.

Frankfurt Airport provides information about the location of services in the airport and about flights, using proximity. The app was installed more than 100,000 times and was rated by 1,388 users, receiving 3.9 out of 5 stars. The majority of users commented that the app was “useless” and had “map” and “logging-in” issues. On the other hand, a few users commented that the app “worked well”.

Silent Beacon is an emergency app that offers several features, such as alert, track, call and notify loved-ones or emergency services in case of an emergency, using tracking features. The App was installed more than 1,000 times and was rated with 4 out of 5 stars by 15 users. We could not identify any problems because of the lack of reviews.

Blicker Bluetooth For Students uses BLE to enable students to send their response to different classroom activities, such as quizzes, so the teacher can see the response on his/her device instantly. The app was installed more than 5,000 times and 44 users rated the app with 4.5 out of 5 stars. The majority of them found the app “useful” and “easy to use”.

The overall evaluation of the ranked applications was from one as the lowest rank to five as the highest rank. The calculation was done as a percentage of each rank by calculating the ratio of the users in the rank to the total users that evaluated the app.The second point for analyzing apps, classifying the factors of acceptance or rejection, was completed by reviewing the users’ comments and finding the pros or cons mentioned. These factors were categorized as follows.

First, satisfaction factors were classified as: (1) “Helpfulness” which defines whether this application helps users to find what they request or not; (2) “Ease of use,” which defines the simplicity of the app to interact with in a convenient way; (3) “Usefulness,” which refers to the utility that resulted from interacting with the app; (4) “Internet connection requirements,” which defines the ability of the app to connect with devices without the need for an internet connection. Second, frustration and dissatisfaction factors were classified as “crashes” and “technical issues” which include all the sudden stops of the app, re-install requests, software updates, and lack of notifications and programming bugs. For example, some apps require subscription fees to obtain their full features, which leads to the rejection of the app by users. This category also includes “sign up” and “log in” issues, where users could not sign up or log in to the app or they could not link their personal or financial data to the app. The category further includes “map failures” which include navigation and proximity determination accuracy.

It should be noted that, according to the users’ reviews, the most positive features that users looked for were the extent to which the application was useful for them and how easy it was to use. Among the applications analysed, seven were desired because of their usefulness and six of them because of their simplicity to use.

The most frequent negative features that users complained about were related to system crashes and map navigation failures. Users of eight of the analysed applications complained about crashes and five of them failed in map information. Table 3 presents a summary of users’ reviews and evaluation.

4 Discussion and Conclusion

4.1 Discussion

The adoption of beacon technology enhances the user’s experience of mobile devices in different ways. The beacons enhance indoor navigation as a replacement for Satellite GPS, thus beacons interact with mobile applications to help users to navigate in an indoor environment. The interaction is specific to each application’s features and purpose. The application analysis (Section 3.2) indicates that most indoor features that have been implemented in mobile applications are map replacement, transit assistant, information guidance and tracking. Most of the applications rely on the beacon proximity feature, where

the accuracy of the user's location is not very important. Also, the wider coverage of beacons and the efficient power consumption make them an excellent choice for indoor deployment.

Proximity-triggered action is one of the most important features of beacons. This feature enables a specific application that provides a service to trigger a specific event when the user enters the range of the beacon signal. Such events come in notification form as advertisements or promotions to engage the users with the environment.

Beacons can also be used as a management tool to improve service quality and user experience by providing features such as queue measurement or handling payment transactions. Moreover, this sort of engagement between the service provider and the user can be used in future analysis to enhance both the service quality and user experiences.

However, using users' data for future analysis without their permission can be considered a violation of their privacy. As stated in the literature, privacy is a challenge not related to the beacon technology but to the applications that use it. In other words, beacon technology relies on a specification used to define small devices to send a signal to receivers. The receivers, in this case, are applications on users' mobile devices which can collect and send data to the application's server for future analysis. One approach in resolving privacy challenges is to have a clear user policy and transparency [16, 3].

Also, application developers must provide users with control options about what information is shared in order to enhance their services. Moreover, location-services in iOS and Android are under the user's control for each application and can be configured at the time of installation or during the runtime [16]. Therefore, the developer must ensure that the user is given sufficient information about the use of data to make an informed decision to allow or deny location services for each app. Developers also need to ensure that users' data are kept secured and encrypted.

Security of the iBeacon protocol is weak because of three vulnerabilities: spoofing, denial of service attacks and hijacking. Some papers [16, 15] indicate that the reason for this security issue is because iBeacon broadcasts its UUID publicly without cryptography and the lack of authentication and encryption of its content. Hackers are able to use these vulnerabilities to impersonate beacons, to drain the beacon's battery, and to change its configuration, which affects the efficiency of the beacon's targeted notifications, tracking/metrics, navigation, and authentication.

However, some companies that use the iBeacon protocol have resolved security issues by using dynamic UUID broadcasting. For example,*Estimote*™ is a company that uses iBeacon protocol in its beacons. The company has developed *Estimote*™ Secure UUID to protect the real ID of the beacon by hiding it and generating a new encrypted Visible ID that changes periodically. The receiver ("the user phone") of the Visible ID communicates with the *Estimote*™ cloud-server to decrypt the Visible ID in order to resolve the real ID which then enables the recognition of the beacon [20]. *Kontakt.io*™ is another company that provides securities solutions for iBeacon. *Kontakt.io*™ Secure Shuffling enables the developer to set random shuffling for the iBeacon's Major and Minor fields which prevents spoofing. Also, the company provides secure and encrypted communication between the beacon and the device that manages it, to prevent hijacking attacks. Furthermore, the company provides a software lock process which deletes the information from the physical beacon when an attempt is made to access it by an unauthorised entity [21].

On the other hand, the Eddystone protocol has a built-in security feature "Eddystone-EID" that encrypts the beacon ID and requires an authorized client to identify its broadcast signal [6]. Therefore, it is important to mention that application developers should use dynamic UUID against spoofing attacks, use time-limited session configuration against DDoS attack and use secure communication and token authentication against Hijacking. These security measurements encourage developers to deploy beacons in the physical world and implement their features within their apps.

Surprisingly, during our application review process, we did not find any comments from users regarding application security and privacy. This might be because users are not aware of the risks. On

the other hand, although users tend to express their privacy concerns regarding sensitive information, they are willing to share it and disclose it to gain benefit from mobile applications, such as customized services, information, and rewards - the phenomenon identified as the "privacy paradox". These findings are in line with few other research conclusions.

In fact, [22] that applications' privacy policies are difficult for users to understand. In order to examine user trust in IoT devices that use beacon protocols, the authors deployed fifteen devices (called 'GNOMES' at Queen Elizabeth Olympic Park in East London) that interacted with users by using a conversational approach [22]. When a user approached the GNOMES within 200 meters, they started a conversation, during which the GNOMES asked the user to share a memory with them. The user had the option to share a memory or not. The result showed that 4007 lines of conversation were recorded between users and GNOMES in three months. This supports the indication that users share personal information, either because they thought this kind of interaction with GNOMES was normal or they were not aware of the information they were sharing [22].

A study [23] examined users' perceived privacy concerns and their privacy protection behaviours about a mobile apps that accessed their sensitive information. The results showed that users' perceived benefits of the app services overcame their perceived privacy concern. This is because their perception was influenced by their information and social needs .The results of [23] showed that users' perceived benefits of the app services (influenced by their information and social needs) overcame their perceived privacy concern.

Also, a study by [24] that examined the influence of the privacy personalization paradox on consumers' decisions about disclosing their sensitive information to gain customized advertainment or information from their provider based on their location (location-aware marketing), showed that privacy personalization overcame consumers' privacy concern, especially when consumers perceived the location-aware marketing as relevant to their needs.

Another study [25] indicated that users of smart TV lack privacy awareness regarding the risk of misuse of their data by the provider or third-party vendors. This is because users' perception of the benefit of the smart TV functionally overcomes their privacy concerns. However, after showing users awareness messages that explained the harm of privacy risks, users were willing to use privacy protection measures on their smart TV provided that it did not compromise their smart TV functionally [25].

Besides privacy and security concerns, applications that implement beacon features provide attractive interaction for users. However, users' satisfaction with beacon features varied across different applications because of the build quality of the application, unclear description of the application, subscriptions fees or the app price. In fact, the review analysis showed that poor quality of app execution has frequently influenced the users' opinion about the beacons' indoor features. Also, several applications had unclear descriptions of their features which made users write negative reviews. Moreover, applications that charged users a price or subscriptions fees, and had functional problems (as mentioned previously), had extremely negative reviews comparing to the free apps.

On the other hand, the most positive satisfaction factors that make users motivated to use these apps depended on the degree to which these apps are easy to use and to what extent these apps provide useful notifications to meet users' needs and raise their satisfaction with the experience.

4.2 Conclusion

In this era of connected environments and devices, our notions have been changed by the new advances of networked systems. One of these advances is BLE beacon deployment. This research has focused on different aspects of beacon protocols that provide unique methods of interaction with applications on mobile OS platforms by exploring the current literature and conducting an analysis of current beacon apps, as well as the degree of user satisfaction.

The literature review showed that beacons used iBeacon™ and Eddystone™ protocols to provide unique methods of interaction with applications on iOS and Android platforms. Also, it showed that beacons' proximity and indoor features provide new user experiences which enhance their engagement with the physical world, using apps specifically designed for hospitals, malls, airports and other massive buildings or city locations. Some issues, raised from the previous research, indicate that app developers should understand beacons' protocol security challenges and vulnerabilities (such as spoofing and hijacking) and use security measures to create a safe environment for both beacons and applications. Also, privacy is another challenge that has gained attention in the literature. Similar conclusions were drawn from the application analysis.

The foremost concern for business owners is how to motivate users, who have poor experiences of beacon-based applications, to download their app and adapt it in their everyday life. The analysis of 26 applications found that there are some technical issues which affect the development of beacon-based apps. One of these limitations is caused by users turning the Bluetooth connection off to save battery life, which leads to reduction in the application's functionality. Lack of precision is another technical issue found in some applications that are used for navigating in indoor spaces. Moreover, users are looking for apps that give them continuity of service delivery without crashing, which was not delivered by some of the analysed apps.

Overall the major challenges for beacons are the security and the privacy of the related applications, rather than the beacon system itself. Another important issue is the reliability of the applications. A lot of users reported facing a sudden crash and the app's unresponsiveness. Even though there are some propositions for strengthening the security and privacy of the applications using beacons, further research is needed to investigate users' perceived privacy concerns and benefit of beacon usage.

Beacon technology is expected to grow rapidly and be used for various purposes through mobile apps including effective advertising tool to attract the attention of customers in business and retail fields. This growth should be kept expanding positively by meeting users' needs and solving their concerns. Moreover, application developers have to improve the usability of their apps and to enhance user experiences. They also should take into account how to build trust with users by letting them control and change their privacy settings. The applications have to be tested thoroughly before public deployment to solve any technical errors. Additionally, business owners need to improve the beacon distribution in order to increase the coverage range and enhance positioning accuracy.

Competing interests

The authors have no competing interests to declare.

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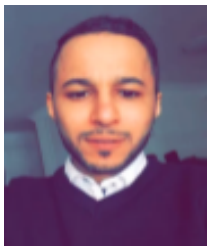

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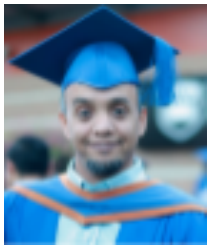

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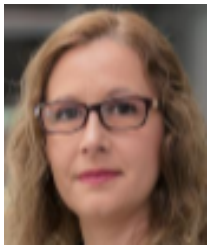

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