Automatic Attendance Control System based on BLE Technology

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Abstract: As an emerging low power wireless technology, Bluetooth Low Energy lately has become an essential part of the Internet of Things world. Its pervasiveness has given the possibility for many different, otherwise manually driven, concepts to work in a different, enhanced, and more automated fashion. In this paper, we present an automatic attendance control system based on the interaction between a modified BLE iBeacon mechanism and users' smart devices. As such, the system can recognize users according to predefined profiles and eventually broadcast valuable information that corresponds to recognized profiles. The proof of concept shows that this is a promising approach regarding automating specific tasks, recognizing users and interacting with them less complexly.

1 INTRODUCTION

Since the release of Apple's iBeacon protocol back in 2013 (Newman, 2014), Bluetooth Low Energy became a dominant technology for many projects in the Internet of Things and human life. From small user appliances to big industry wireless solutions, everything is trying to be connected. With an estimated 21 billion devices possibly connected by the year 2020, data generating a massive amount of data becomes a usual daily routine. With that said, businesses can no longer ignore such growth and should adjust to this revolution swiftly. Along with the IoT, a new concept called "The Physical Web" embedded itself into BLE technology and lately is on the rise. Such idea allows us to connect the physical and virtual world with each other. Better said, it enables us to interact with the objects that surround us, such as user appliance devices. The product of such interaction is sharing and processing of different data to gain a better knowledge and to facilitate everyday activities.

Surely, with the smart environment and the IoT, the door to different technological approaches, where devices share essential information is wide open. We do see that BLE is taking over the world, mainly in the consumer device area, where the whole ecosystem proceeds to grow continually. Especially with the latest BLE concept called Bluetooth proximity beacons often referred to as the Beacons (ibeacons), where LE peripherals advertise themselves to the nearby devices by using advertisement packets (Martin et al., 2014).

An iBeacon represents an electromagnetic signal that can be processed by every BLE enabled device. In more details, iBeacons are small transmitters that advertise a specific BLE payload that is represented by particular identifiers: UUID (Universally Unique Identifier) 128-bit value, Major value (16-bit unsigned integer), and Minor value (16-bit unsigned integer). The last two values are optional and are included in case of more hierarchical system implementations. As already said, an iBeacon signal can represent a specific object or process in some defined environment. Later, when received by a BLE enabled device, that signal triggers some action that means something to the user or some other object.

Nowadays, numerous beacon maker companies exist, and every company has something different to offer. Their products differ in various sizes, functionalities, but the majority of them are static. In other words, a single beacon device can only broadcast one iBeacon combination of UUID, Major, and Minor values at the same time, and any further classification is handled by the application that is usually installed on the users' smartphones. If we want to broadcast different type of data, we need another beacon device with separate iBeacon combination. Developing an app became a primary focus and the central point of all the processing, leaving the iBeacon hardware as a static device without any advanced functionality. As already mentioned, many solutions exist on this subject, but most of the processing is done on the application side. In most cases, it became mandatory for

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the user to have an application installed on his smartphone. Let us not forget that the beacon device initially can not collect BLE signals since it is a one-way broadcasting technology.

To overcome such a static method of broadcasting iBeacon BLE signal, in our previous work we have proposed a dynamic solution where a modified BLE beacon device can simultaneously transmit and receive different signals according to various user profiles (Boric et al., 2018), as well as the implementation part and the challenges (M. Boric et al., 2018). By modified beacon, we refer to a device that in the same moment can work in a scanning mode, and an iBeacon mode (advertising specific information to corresponding users) (Townsend et al., 2014). Additionally, these two modes complement each other, what allows the device to broadcast information to a specific group of users that share the same profile. The profile can be created manually by predefined taxonomy, or automatically by users' movement post processing and detailed analytics. For this simultaneous broadcasting of information to different profiles, the device needs to have a particular mechanism and the background infrastructure that allows the profile recognition and the broadcast. Now, we are expanding that system with real-world examples to show its usage and benefit for different purposes.

The recognition concept above could contribute to solving the problem of manual presence detection through automatically collecting users' smartphones BLE signals in any scenario environment where such detection is required. To show the proof of concept we utilize the mentioned system for collecting students' lecture attendance in the academic environment. Our scenario experiment took place at the Faculty of Engineering and Telecommunications of Vigo in Spain. We have planted one beacon device in the hallway, for testing the dynamic beacon broadcasting, and another device in one of the classrooms of the Faculty for collecting student attendance.

The experiment was conducted in a one-month period, and we present the details in the following sections. In this work, we show how our dynamic system can be used in the academic environment to automatically collect students lecture attendance when students are in beacon proximity, without any application installed on the user side. However, with the application installed on the user side, a system may eventually broadcast information to him, e.g., different events, classes timetable, homework, faculty changes, and so on.

The remainder of this paper we divide into several sections. Section 2 gives the related work and what was our primary motivation. Part 3 explains the system architecture and how we use it to for proposed system. In section 4 we present the implementation part with the results, wherein section 5 we conclude the paper.

2 RELATED WORK

Researchers have been advancing in the Bluetooth Low Energy field lately. This progress gave some great examples of the use of such technology in today's world, from retail business (Shende et al., 2017) and giving a better experience to the customers, to monitoring different processes in industry or health (Srinivasan et al., 2016) (Komai et al., 2016). When speaking of beacon involvement in the academic environment, few projects have been proposed and deployed. Researchers in (S. Barapatre et al., 2017) have proposed the smart college management system with the ability of automatic student class attendance. However, for the system to be able to recognize a particular student, a student has to use an Android app and to mark his attendance during a particular class. Similarly, authors in (Apoorv and Mathur, 2016) have built a system that facilitates the teachers to collect student attendances. For this purpose, the Android application communicates with the BLE beacon planted in the classroom and collects the sensor data, from ID cards, that matches the student's attendance. However, to collect attendance, a teacher has to collect all the BLE signals manually through the app.

Furthermore, authors in (Saraswat and Garg, 2016) are using beacons for faculty administrative tasks and interacting with the students by sending them Web links and the corresponding notifications. Another feature of this system is the automatic student attendance collection, where students according to their stay in the classroom, during particular lecture, get recorded by the system. That said, when the specific student is near beacon a clock time starts in the application background automatically and according to its proximity (near, immediate), local clocktime increases. However, the majority of the work is done on the application side (student's smartphone). In our case, a dynamic beacon is the focal point of all the processing that includes sending information to the students, collecting their attendance, analyzing their building usage and giving an insight to the faculty personnel.

Also, the reason for electing BLE technology is because of its low power consumption, comparing to Wi-Fi for instance (Putra et al., 2017). Also, Wi-Fi technology asks for previously established connection between two hosts which is not convenient in our case. In case of the Wi-Fi direct and classic Bluetooth, they ask for secure pairing to unknown devices (Trifunovic et al., 2011).

3 SYSTEM ARCHITECTURE

The idea is to have a unique system that recognizes users while in a proximity of a beacon and triggers some actions based on that recognition. The user's smart device can be used to monitor the proximity location of a user in the beacon vicinity. Based on this location information, a user's presence record will get updated automatically on the system. For better understanding, we will take the example of students lecture attendance. Usually, when students enter a specific classroom, a professor manually checks the students' participation, either on a piece of paper or using some application. This kind of work is time-consuming and introduces complexity in further school analysis, e.g., If the school board wants to get better student/classes/subject insight, everything has to be done manually. However, by using BLE in combination with the student's smartphone, or some other BLE enabled device, this work can be automatized and can save much time for the future faculty analysis.

For better system explanation, we give the concept in Figure 1, where the beacon device works in two modes, the discovery, and the advertising mode that uses the iBeacon technology. The discovery mode, as already mentioned, is in a constant search for the nearby devices (BLE devices) and the advertising mode optionally sends some relevant interest-based data to the recognized users. When a particular user enters a classroom (broadcasting area), his smartphone BLE MAC address gets recognized by the classroom beacon device that works in a discovery (passive scanning) mode. For the user to be identified, it is not obligatory to have an installed application on his smartphone, or even connect to the system since the user is recognized automatically. Next, the beacon device sends the user's BLE MAC address to the database through the back-end infrastructure. The back-end can be based on any connection technology, or even implemented on the same device where the beacon functionality is installed. In our case, it is installed on one of the Raspberries and connected via secured Wi-Fi connection. To send some information to the recognized user, we need to use the advertising mode of the beacon device (iBeacon mode). However, this step is optional and asks for an application on the user's side.

The database is nothing else but a student repository where all his relevant data is saved (Student year, subjects, classroom he attended and time, personal info, and so on.). Personal user information can be inserted through the faculty information system, while all the other information (student movement activity) can be collected from the database. Also, the database contains a student attendance report of his every attendance, for which the beacon device is used in the first place. In that case, the system would suffer from false attendance inputs. This presence is not marked at the same moment when the student enters the classroom but after a specific period. This period depends on how the faculty organizes and schedules their classes, and also how does it handle students attendance. For example, if the faculty agrees for the lessons to be held for 2 hours than the beacon device can be configured in that manner. A minimum number of student acknowledgments by the system, during the lecture time, is flexible and configurable, and it is a subject of a faculty policy, as mentioned before. If the student is present in the classroom during the whole lecture period (e.g., two hours), the system marks his attendance as the database record.

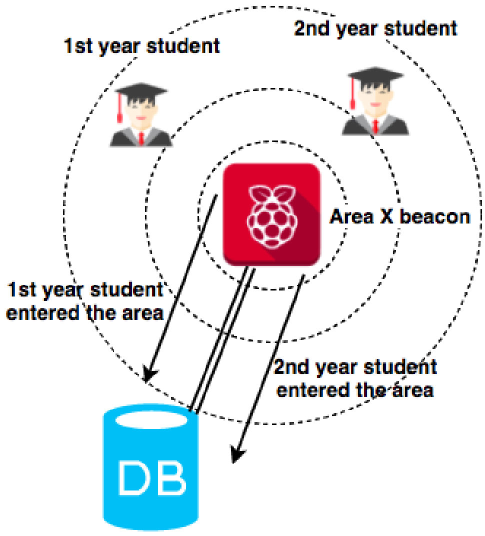

Figure 1: Dynamic beacon functionality.

Nevertheless, we have to consider a problem of the signal overlapping, especially if the beaconing areas are a close one to another (two classrooms, offices, and so on). For example, if two students are attending classes in the different classrooms, and the classrooms are close as mentioned, it is possible for the signal to overlap. This behavior would result in collecting false data. In that case, the system would not correctly process the inputs, and the output would not be trustworthy. Even with the excellent and planned site survey, we have to take into account a certain amount of false positives. First, a precise positioning of the beacon device and the proper site survey of the classroom need to be done. Second, an additional mechanism to prevent such behavior needs to be introduced. In our case, that is a door scanner positioned correctly at the classroom entrance, so that the system can scan students when entering the room. For that matter, we can use the infrared technology or something similar and connect it and configure it to the Raspberry device, dynamic iBeacon in our case. The beacon device can work simultaneously for many different profiles. In other words, it can recognize different profiles, if profile recognition is implemented into the database. In this case, all we need is one beacon device per every classroom. That said, we lower the broadcasting congestion and network latency that represent the problem for most of the IEEE 802 networks. The beacon device does not have to be a part of the school infrastructure (school Wi-Fi, Ethernet, and so on).

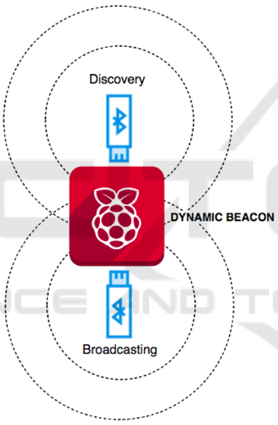

Figure 2: Beacon device architecture.

Although, every beacon device has to connect to the central beacon repository. In our case, this repository is the database. As mentioned before, for the beacon to function dynamically, constant connection to DB is necessary. This way, the beacon advertiser is changing his beacon combination ID, depending on profile entrance and, if needed, disseminates the corresponding information to the users. Every profile is represented by a different combination ID (UUID, Major, and Minor number). The most critical piece of information for the system to be functional is the user's device MAC address with which the system recognizes a particular user and his profile. A user device does not have to be his private mobile phone explicitly, but any piece of hardware that supports BLE (BLE token, smart card, and so on). However, if we want to utilize a full system capacity, advertising information to the students, using smartphones represents a better approach. For the system to work appropriately, student phone MAC addresses need to be inserted into the database before the student attendance collection. Achieving beacon to operate in a dynamic mode is not an easy task. Usually, beacons work in a static mode where every beacon signal identifier (UUID, Major, and Minor values) corresponds to only one information, and they were initially imagined as such. However, having many beacon devices in a single area brings network latency and congestion, as mentioned before. To overcome that problem, we offer a solution where beacon device recognizes the users dynamically when near the discovery/broadcasting area. Dynamically means that the beacon can serve and acknowledge many user profiles simultaneously without degrading its functionality (see Figure 2). In our case, we use such solution for automatic student attendance, as mentioned earlier. Additionally, if positioned correctly (along the faculty area), the beacon system can collect all the faculty users on a regular basis and save them into the database. That said, this information could be valuable for building managers for better space analytics, building management, on so on. If so, the faculty board can use this insight for different future planning regarding their assets and faculty management.

4 IMPLEMENTATION AND THE RESULTS

As already mentioned, a single beacon device contains two major parts; the discovery (scanning) and the advertising part (iBeacon) where every element works separately and includes its methodology. That said, for the beacon device we use a Raspberry Pi small computer and corresponding BLE USB module devices that play a vital role in the dynamic broadcasting. Beacon device is based on Raspberry Pi 3 Model B device along with the Bluetooth 4.0 CSR8510 USB Module. Reason for this is because the Raspberry device is Linux based and in that manner, it is very flexible and scalable for this kind of solution. One BLE USB module device is used for the discovery part, while the other for advertising part (see Figure 2). The beacon device is connected to the database, "Student Profile DB" in our case. We have to mention that the database can be implemented separately from the beacon device on a different device, or it can be installed on the same device where the beacon resides. This implementation is possible due to the flexibility of the Raspberry Pi Linux operating system. "Student Profile DB" is based on the MySQL open-source relational database management system. It is worth mentioning that detailed database structure is not presented since it was not relevant for the paper. In our case, a single dynamic beacon device is planted in the middle of the ceiling of one of the classrooms, for the uniform distribution of signal, and it is activated to work in a discovery mode (see Figure 3).

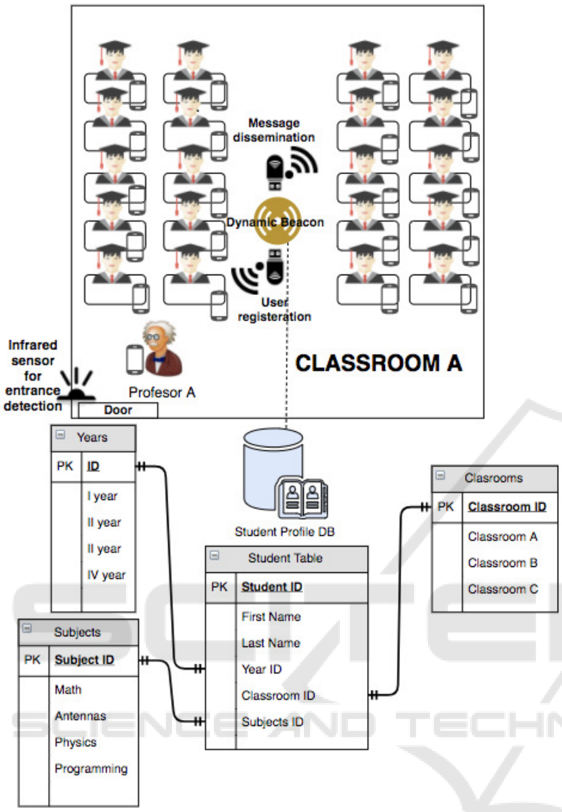

Figure 3: System architecture.

To evaluate the performance of the proposed system, we have conducted an experiment on the premises of the Faculty of Engineering and Telecommunications of Vigo in Spain. To show that single beacon device is capable of acquiring different user profiles, we planted it in one part of the faculty area and gathered information during a short period. As already mentioned before, user profiles had to be implemented, according to some taxonomy and inserted into the ”Student Profile” database. We were able to recognize and collect four users simultaneously what can be seen in Figure 4. From the Figure 4 we can see that the device after recognizing specific profile (user), by scanning his phone's MAC address, it activates the script for some information distribution. The device broadcasts an iBeacon combination ID (UUID, Major, and Minor values) that corresponds to a particular user profile. An example of the iBeacon combination and how the BLE advertising device (hci1) is

```
PhD STUDENTS iBEACON...
< HCI Command: ogf 0x08, ocf 0x0008, plen 32
  1E 02 01 1A 1A FF 4C 00 02 15 E2 0A 39 F4 73 F5 4B C4 A1 2F
  17 D1 AD 07 A9 61 00 06 00 01 C8 00
> HCI Event: 0x0e plen 4
  01 08 20 00
Complete
TEACHING ASSISTANTS iBEACON...
< HCI Command: ogf 0x08, ocf 0x0008, plen 32
  1E 02 01 1A 1A FF 4C 00 02 15 E2 0A 39 F4 73 F5 4B C4 A1 2F
  17 D1 AD 07 A9 61 00 09 00 01 C8 00
> HCI Event: 0x0e plen 4
  01 08 20 00
Complete
II_YEAR_STUDENTS iBEACON...
< HCI Command: ogf 0x08, ocf 0x0008, plen 32
  1E 02 01 1A 1A FF 4C 00 02 15 E2 0A 39 F4 73 F5 4B C4 A1 2F
  17 D1 AD 07 A9 61 00 02 00 01 C8 00
> HCI Event: 0x0e plen 4
  01 08 20 00
Complete
RESEARCHERS iBEACON...
< HCI Command: ogf 0x08, ocf 0x0008, plen 32
  1E 02 01 1A 1A FF 4C 00 02 15 E2 0A 39 F4 73 F5 4B C4 A1 2F
  17 D1 AD 07 A9 61 00 11 00 01 C8 00
> HCI Event: 0x0e plen 4
  01 08 20 00
Complete


log records from log temp table:
PhD student just entered te area, activating the script
Teaching assistant just entered te area, activating the script
II year student just entered te area, activating the script
Researcher just entered te area, activating the script
```

Figure 4: Simultaneously recognized users.

activated before sending the corresponding combination ID can be seen from the Figure 5. Let us not forget that for the notification part, an application has to be developed and installed on the users' smart devices.

```
#!/bin/sh
export BLUETOOTH_DEVICE=hci1
export UUID="e2 0a 39 f4 73 f5 4b c4 a1 2f 17 d1 ad 07 a9 61"
export MAJOR="00 13"
export MINOR="00 01"
export POWER="c8"
echo "VISITORS iBEACON..."
sudo hciconfig $BLUETOOTH_DEVICE up
sudo hciconfig $BLUETOOTH_DEVICE noleadv
sudo hciconfig $BLUETOOTH_DEVICE leadv 3
sudo hcitool -i hci1 cmd 0x08 0x0008 1e 02 01 1a 1a ff 4c 00 02 15 $UUID $MAJOR$
echo "Complete"
```

Figure 5: Combination ID script activation.

To acquire student attendance, we planted another beacon device in one of the classrooms for precisely one month and monitored the lecture that students had on Monday's from 9 h to 11 h. After collecting and processing all the data (students' devices MAC addresses), the results were following: a) four users were recognized continuously during the periods of the lecture on different days (18th, 25th of September, 2nd, 9th of October) (see Table 1). b). All the users were recognized by the system approximately every 5 minutes, which is satisfying if we consider that the beacon was configured to discover users the same amount of time. The beacon device could have been configured to collect the student attendance after less amount of time. However, in our case, that was not necessary since we found convenient that a five minute period was more than enough. We have to take into account that student entered the classroom pretty much around the same time. On the other hand, they left the class at different times (September 18 of at 10:50 h, September 25 at 11 h, October 2 at 10:41 h, and on the 9th of October at 10:29 h) (see Table 1). Furthermore, two users that were not part of the class were discovered by the system on October 9th. This behavior is probably due to the signal overlapping what we explained before in the paper. Also, the students do not meet the class period requirements since they were only recognized once in two hour period, and we can consider them as not valid for the specific lecture attendance list.

Table 1: Recognized users in the classroom.

	Classroom 218			
	08:57 - 10:50	**09:01 - 11:00**	**09:01 - 10:41**	**09:03 - 10:29**
User	**18/09**	**25/09**	**02/10**	**09/10**
Hanna	25	29	20	16
David	24	27	21	19
Marion	26	31	25	19
Anna	28	30	21	17
Jane				1
Luke				1
Average	**5**	**4**	**6**	**7**

We have to mention that no influence on users was done, regarding their smart devices and activating the BLE protocol, whatsoever. Also, for the sake of user privacy, we had to change users MAC addresses for randomly generated names.

5 CONCLUSION

Even though beacon devices are becoming more popular and it is evident that lately are included in many research and business projects, their potential is underutilized. That said, the majority of processing is handled by the application, which resides on a user's smartphone or some other compatible device. However, letting the software part to do all the processing can become application saturated, and if we take into account that today's users have many apps installed on their device, the problem is evident. In this work, we presented the solution where a part of the processing job is shifted and assigned to the beacon device. Such method can help us to overcome the early mentioned problem of possible application over-processing. It does that by recognizing and serving simultaneously many user profiles and can have a significant potential in any message dissemination or collecting data environment.

This method of including beacon device into more active processing and system involvement according to particular inputs can be used in many areas. It makes it even easier since Raspberry Pi accepts broad types of sensors for different requirements and it makes a perfect device for any beacon solution. That being said, we give an indicative list of applications where this solution can find a use:

- Space analytics, where users are monitored through their movements while using building assets. Such analytics are especially useful for building managers and their future planning of building expansion and better management of the building environment.
- Hospital system and indoor localization, where the patients are divided into different groups and the hospital personnel are in charge of its patient group. This way the doctor when in beacon proximity can receive an instant update and the location of his patients without any extra processing.
- Any extending of cloud computing to the edge of an enterprise's network, better known as Fog computing, where the operation of computing, networking services, and storage is facilitated between end devices and cloud computing data centers.

In this work, we offer preliminary results, and for the future work, we plan to implement the system through all Faculty areas and along with obtaining student attendance through more extensive tests. We also expect to pair the dynamic beacon solution with the corresponding application. The application would be installed on users' phones and interact with students on a daily basis by sending them interest-based information. The additional part would be collecting student movement data that later would be processed for better space analytics.

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