LOCALIZATION OF MEDICAL DEVICES BASED ON BLUETOOTH LOW ENERGY (BTLE)

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ABSTRACT

Wireless devices have invaded the medical industry with a wide range of capability as components of a wireless personal area network (WPAN) and Wireless Body Area Network (WBAN). The recent advances in Internet of Things (IoT) promises even larger contributions to the future of medical applications. This paper investigates the Bluetooth Low Energy (Bluetooth Smart- BTLE) for indoor localization of HealthCare devices used in medical telemetry applications and demonstrates the key role that localization plays in tracking of Bluetooth Low Energy enabled medical devices. Proper tracking of these devices provides better management which would directly reduce the transmission of infectious diseases which can result from improper sharing of these devices. This work will investigate the novel indoor localization technologies of BTLE devices with creative research strategies, and their applications as a basis for ultimately improving health standard using BTLE localization.

Key words: *Localization, BTLE, healthcare, Medical Devices*

1. INTRODUCTION

In Canada in 2007, there were 1077 reported cases of acute hepatitis B infection. In late 2006, five residents living in the same unit of a long-term care home (LTCH) in Toronto, Canada became infected with Hepatitis B Virus (HBV). This report describes the outbreak investigation and epidemiological analyses of this outbreak of acute HBV infection. All residents in the LTCH were serologically screened for hepatitis B markers. The infection control practices of the LTCH and of high-risk services provided to residents were reviewed. The risk factors for HBV transmission were investigated among residents and a case control analysis was conducted to identify associations with acute HBV infection. Results In total, five cases of acute HBV infection were identified in the same unit of the LTCH. The attack rate was 20.8% and the case-fatality rate was 60%. All five cases had diabetes mellitus, and HBV transmission was significantly associated with blood glucose monitoring. Conclusions results of this outbreak investigation and analysis demonstrated that hepatitis B transmission was associated with shared blood glucose monitoring equipment. To prevent hepatitis B transmission, it was recommended that a glucometer and finger-stick device be assigned to each diabetic resident requiring blood glucose monitoring in addition to following routine infection control practices [1]. Similar incidents have been investigated in [2].

Currently most of the medical devices such as a blood glucose monitoring devices are Bluetooth enabled. As a result these devices can be vulnerable to attacks related to this technology [3]. On the contrary this technology can be exploited to track these devices indoors in a medical facility. Proper tracking of the devices can enable to control or manage the sharing of these devices. Thus, we can reduce the transmission of infections associated with an improper sharing of these medical devices.

2. BACKGROUND

Bluetooth low energy is designed to enable new markets requiring low latency, low cost, low duty cycle and low power consumption data devices. These markets include healthcare, proximity, fitness, automotive, and smart grid applications. These may include device categories that are completely new to Bluetooth technology, or will use multiple features such as low energy and high speed Bluetooth technology within the same device.

Bluetooth Low Energy [4] devices operate in the 2.4 GHz license-free band, and so share the same indoor propagation characteristics as 2.4 GHz WiFi transceivers. The beaconing, or advertising mode, permitted in the BLE standard enables a very short, unsolicited message at very flexible update rates. These messages can be used to allow a device to detect close proximity to a specific location based on the Received Signal Strength (RSS). In this way, location specific triggers, adverts, vouchers and information can be provided to the user.

2.1 BLUETOOTH LE IN MEDICAL DEVICES

Embedding Bluetooth in medical devices has been transforming medical industry for the last decade. If we imagine the application of sensors in Healthcare which employ Bluetooth low energy, the possibilities and opportunities are diverse: continuous EEG monitoring with overlay of patient activities that would be triggers to epileptic activities (medical hat), 24 hour vital sign and ECG monitoring coupled with physical activity profile (medical underwear), simultaneous monitoring of airway resistance, environmental pollutants and actual medication delivery (medical inhaler), oximeter capable of adjusting the positive pressure to the changes in carbon dioxide concentration in the exhaled air of the user, ingestible cameras capable of real time transmission of the images to image processing module, and many others. These devices offer additional data that can be used to create more interactive, and health monitoring an activity of daily living.

2.2 BLUETOOTH LE BEACONS

BLE advertising beacons are particularly attractive to retailers because of the promise of long battery lives of many years, and so low maintenance requirements. Long battery lives are expected to require low radio power output and/or low beaconing rates. While this does not affect their use for proximity detection it does affect their usefulness for providing fingerprint-based positioning throughout an entire indoor environment.

Beacon device is a relatively new technology, first introduced by Apple in 2013. Since then, this technology has been put into tremendous use in the retail sales. Now Apple and Google have come up with their own beacon standards, "iBeacon" and "Eddystone". Beacons work on Bluetooth Low Energy – BLE (BTLE) which transmit a signal up to a certain distance, ranging from 15cm (~6 in) to 70m (~230 ft). Beacons provide a virtual region, when we scan the specific region of beacon then we can say that we are within that region. Beacon broadcasts Bluetooth signal which contains unique information of itself frequently, so the coverage area will be filled with beacon's signal; the area is called Beacon Region.

The beacons used in this work are Estimote beacons [5]. These beacons have broadcasting power (or transmitting power) which ranged between -40dBm to +4dBm, advertising interval of 100ms to 2000ms, RSSI.

3. BLUETOOTH LOW ENERGY LOCALIZATION FOR HEALTHCARE

Although there is no specific support for positioning service in Bluetooth technology yet the predominant technology used are signal strength measurement, link quality and bit error rate which rely on the services of the Host Controller Interface**.** Thus the Received Signal Strength Indicator (RSSI) value of the Bluetooth signal is used to get a correlation in the distance between sender and receiver in a network. RSSI value fingerprinting using Bluetooth Low Energy signals can be used for localization similar to the work in [6].

The work in this paper exploits BTLE signals detected from Estimote beacons to identify rooms in the LTCH scenario. The BTLE signals from medical devices (e.g. Glucometer) to identify the proper assignment of these devices to the correct room. The Glucometers used in this work are One Touch Verio Blood Glucose Monitoring Systems which are BTLE capable [7]**.**

The main reasons for using the Beacon technology are the following:

- Rely on BTLE which is low power consumption, can work 24 hours 7 days over a year with a button cell battery, very small and it can be installed very easily.
- High supported range.
- Cross-platform and support wide range of devices BLE is supported by different platforms including Android, IOS, and Windows… etc. In addition, according to Bluetooth SIG, they predict that "by 2018 more than 90 percent of Bluetooth enabled smartphones will support Bluetooth Smart" 2. Therefore, we can say BLE or Beacon is a trend in future.

3.1 ALGORITHM DESIGN

For the algorithm to work we need two data sets which store the offline data. The first data set is as specified in Table 1 (mapping of Room ID vs Medical Device) and the second one is as in Table 2 (mapping of Beacon Identifier vs Room ID).

To detect the identity of the rooms in the LTCH scenario, we apply the concept of proximity zones. These proximity zones are distance measurements correlations from the RSSI values of the BTLE signals of the beacons.

Proximity zones are defined as [5]:

- immediate (very close to the beacon)
- near (about 1-3 m from the beacon)
- far (further away or the signal is fluctuating too much to make a better estimate)
- unknown.

If the proximity to nearby beacon is immediate, we use the identifier of the beacon for mapping to the identity of the room.

Algorithm: Medical Device Localization

1. Scan Estimote Beacons
   Using proximity zones, Identify the Room Identity by mapping the immediate Estimote beacons identity to the room identity. This principle makes use of Table 2**.**
2. Scan BTLE devices and filter the closest devices based on range and map the values with the devices in Table 1 where we find the devices from the list of devices allocated in the health care.
3. By using the room identity from Step 1, we can use the Table 1 to identify the Glucometer assigned for the particular room.
4. Using the mapping from Step 2, we can detect the Glucometer detected in the room.
5. If the Glucometer detected at Step 4 matched with the Glucometer assigned in Step 2, the assignment will be labeled “correct” else “wrong”.

Room ID	Glucometer (Mac Address)
141	F1:9F:7C:9F:0E:32
142	E6:1A:1A:6F:8C:43

Table 1: Room ID vs Medical Device

Estimote Beacon (Identifier)	Room ID
79a00688289bb9a713b897f8ef7e4d26	141
635ba5bb64ad0ea4e0db58d75f98162d	141
6abde74a4fae5a320ddb7d9978a45523	141
7ed22602334736ebdf9d7f49e7a39f2f	141
302b8565852e5f88014b4e34c123b71c	142
1c02b18fdaa395b11df1a5f2fdd7fe0a	142
32309c1d1eca0b12b118b1661056260b	142
f9ec6608dd55c381298b97629502c838	142

Table 2: Beacon Identifier vs Room ID

The closest BTLE devices are determined using attenuation model. The RSSI (in dBm) which is the ratio of the transmitter power and the received power decreases exponentially as the distance increases. This relation is given by equation (1)

$$RSSI_{dBm} = -10 * n \log_{10} d + A \tag{1}$$

The relationship between d and RSSI

$$d_m = 10^{\frac{RSSI-A}{-10*n}} \tag{2}$$

Where, n: signal propagation constant, also named propagation exponent (n=2 for free space) ; d: distance from the sender; A: received signal strength at a distance of one meter (in our case it is equivalent to Tx Power =-65dBm).

The distance (accuracy) property measures the correct RSSI and is calculated from the average RSSI over 9 samples.

3.2 EXPERIMENTAL SETUP: STANDALONE ARCHITECTURE

In case of the standalone architecture, the localization algorithm is implemented in a single Android App. In other words, one Android application is developed which makes use of the data sets (tables) to perform the BTLE medical devices localization. The tables of data sets are small in size. As a result, these values are coded as a hashmap. But future work will extend the implementation of these data sets as XML files which can be stored in the SD card of the device in order for the application to parse and use them accordingly.

The experiments conducted in this work are based on the standalone architecture. A single android application which can scan Estimote beacons and BTLE devices such as Glucometers. Based on the scan results the algorithm in section 3.1 is used to detect the correct assignment of a Glucometer to its respective room which it was assigned beforehand verifying the device is not misplaced.

3.3 EXPERIMENTAL SETUP: CLIENT-SERVER ARCHITECTURE

This section discusses the conceptual design to how the Cloud infrastructure of the Estimote can be used for BTLE localization. This design can be used equivalent to the design in section 3.1 and 3.2. This involves building our own App using the Estimote SDK.

With the Estimote SDK, we can easily implement Indoor Location in our own app. The Indoor Location SDK enables us to:

- Set up a location manually (draw a room with coordinates).
- Embed a built-in Location View - a map of location with the current position marked on it.
- The Location View is fully configurable – the appearance can be customized, show or hide labels or leave trace of the movement.

- Get raw positioning data – such as coordinates (x, y) and orientation.
- Save and load locations to and from Estimote Cloud.

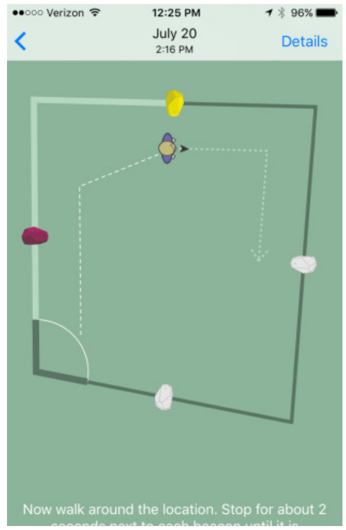

Figure 1: Estimote App for Beacons Placement

As can be seen from the Figure 1**,** we can scan walk around the room which we can to include in our localization and the app suggests the number and location of placement of the beacons properly. Once this phase is completed, we can use an application token to access our beacons for localization.

4. RESULTS

The experiment conducted in this work is based on the stand alone architecture described in section 3.2. The testing area used for the localization includes two adjacent rooms of the Schaffer engineering building of Morgan State University. These two rooms are as shown in Figure 2 and represent an LTCH scenario.

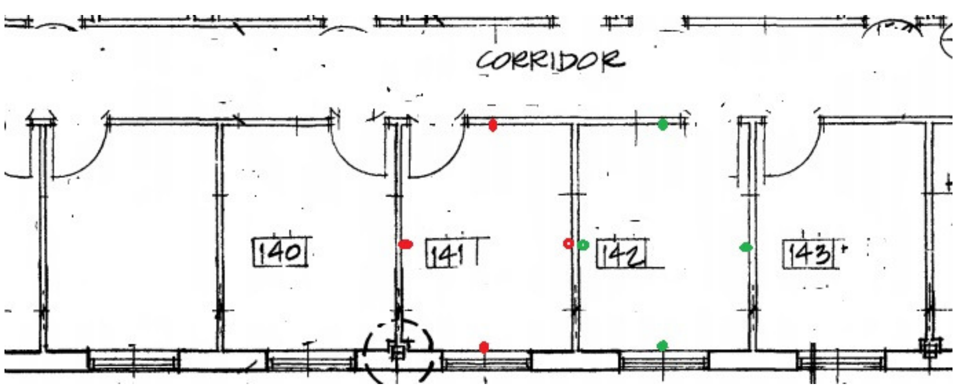

Figure 2: Layout of Testing Rooms

As can be seen from the Figure 2, 4 Estimote beacons are installed in each of the rooms (Room 141 and Room 142) for localization. As the Estimote beacons are powerful, it could be possible to identify a room identity using only a single beacon but we used four Estimote beacons for a

future extension of enabling the application navigation capability which can continuously display the user (device) location on the map of the building. The Estimotes are installed as shown with the red and green dots in each of the rooms.
The physical installation of the Estimote beacons is as shown below in Figure 3 which shows two Estimotes on their respective walls as an example.

Figure 3: Physical Location of Estimote Beacons

Using the Android App which runs the algorithm in Section 3.1 we can scan the Glucometer assigned room 141 as an example to show the working of this application. The result is as shown below in Figure 4.

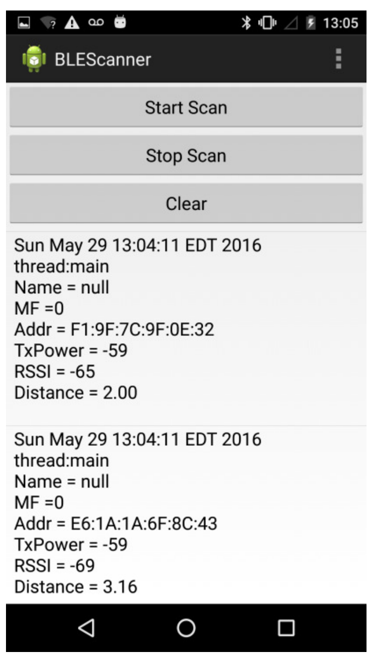

Figure 4: BTLE Device Scanner

The BTLE scanner App shows the scan result of reachable BTLE devices. For each of the detected devices the result includes the mac address, Tx Power, RSSI, and distance calculated.

From the scanned devices, candidates are filtered based on distance and compared to the device to room identity mapping table and the proper assignment of the device (Glucometer) is determined.

As can be seen from the first entry Figure 4, the first entry BTLE device has a mac address " F1:9F:7C:9F:0E:32" and it is located around 2m from the mobile device used for scanning. Using the Glucometer localization App in Figure 5, this BTLE device is detected when the "SHOW DEVICE" button is clicked. The detected device and the already assigned device in the table are matched. As a result the assignment status is set as "Correct". The also determines the identity of the room based on the proximity zone of the detected beacons.

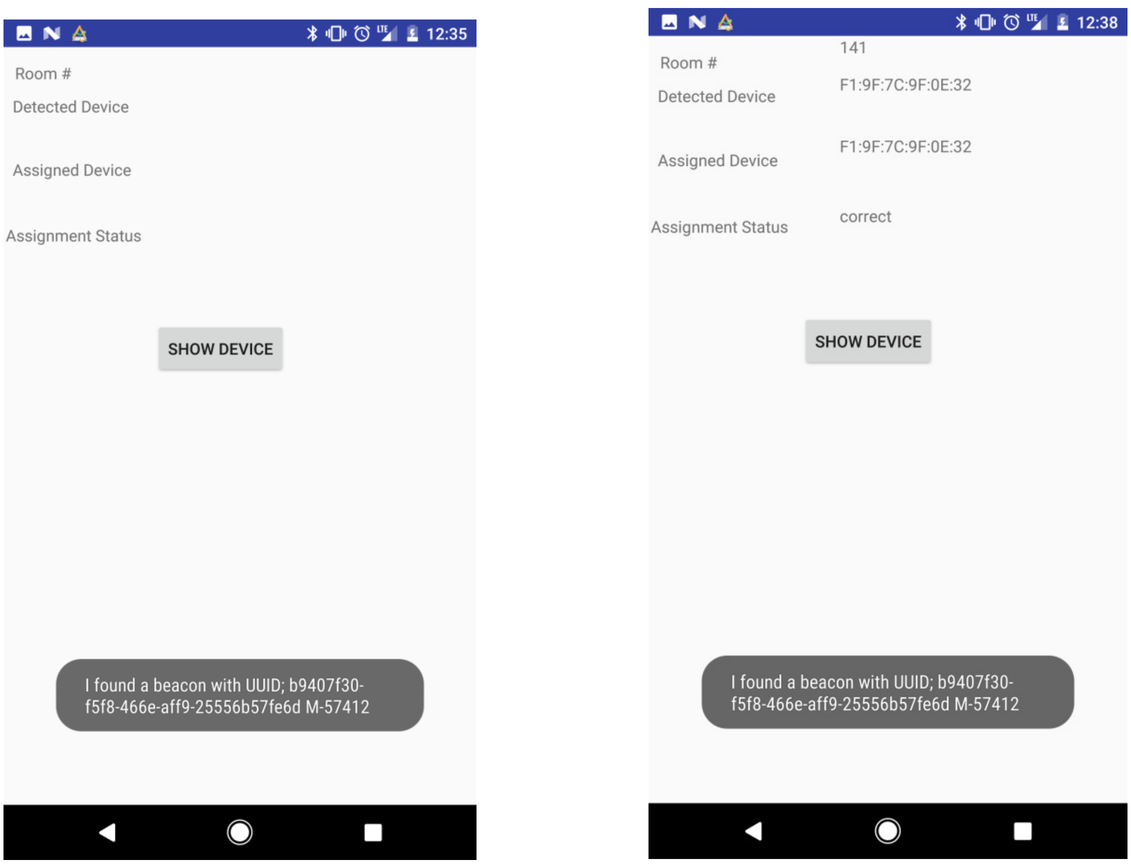

Figure 5: Glucometer Localization App

5. CONCLUSIONS AND FUTURE WORK

This work highlights the potential for use of commercial technology such as Bluetooth in telemetry applications in a long term health care. The use of wireless telemetry technologies such as Bluetooth Low Energy in medical environments brings major advantages to the existing

HealthCare medical services. The experimental work achieved shows how this Bluetooth Low energy technology which is currently available in many medical devices can be used to properly track these medical devices in a long term care home scenario. Using this localization technique can help to properly track these medical devices for better management which would directly reduce the transmission of infectious diseases which can result from improper sharing of these devices

Future work will investigate expansion of the indoor localization technique implemented here over a bigger testing area. In addition, it will integrate the navigation capability by loading the map of the testing area besides to locating the medical devices.

6. ACKNOWLEDGEMENT

The research reported in this publication was supported by the National Institute of General Medical Sciences of the National Institutes of Health under Award Number UL1GM118973. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

7. REFERENCES

[1] Consu Sachdeva, Herveen; Green, Corey I.; Arthur, Anne; Andonov, Anton P, “Risk factors associated with a nosocomial hepatitis B outbreak in a long-term care facility in Toronto”, C*anadian Journal of Infection Control . Spring2012, Vol. 27 Issue 1, p9-14*

[2] Matthew E. Wise et.al., “Outbreak of acute hepatitis B virus infections associated with podiatric care at a psychiatric long-term care facility”, *American Journal of Infection Control* Volume 40, Issue 1, February 2012, Pages 16-21

[3] W. K. Zegeye, F. Moazzami, R. Dean. Y. Astatke, "Exploiting Bluetooth Low Energy Pairing Vulnerability in Telemedicine," " *in proceedings of the 51st International Telemetry Conference (ITC)*, Oct. 2015, Las Vegas, NV.

[4] Bluetooth SIG. Bluetooth Specification Version 4.0, 06 2010.

[5] Estimote, retrieved from https://estimote.com/, August 6, 2017

[6] Wondimu K. Zegeye, Seifemichael Amsalu, Yacob Astatke, Farzad Moazzami, “WiFi RSS Fingerprinting Indoor Localization for Mobile Devices,” The 7th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (IEEE UEMCON 2016), New York City, NY, USA 20 - 22 October 2016.

[7] OneTouch Verio® meter, retrieved from https://www.onetouch.com/products/glucose-meters/onetouch-verio, August 6, 2017