Smartphone Applications for Indoor Real-Time Location Systems (RTLSs) with Bluetooth Low Energy

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Abstract: The benefits of Hospital real-time location systems (RTLSs) have been characterized as increasing efficiency and reducing operational costs. We developed iPhone applications for an indoor RTLS with Bluetooth low energy (BLE) and evaluated the system in our laboratory rooms instead of on actual hospital wards. The applications were installed in peripherals as tags on iPhone5s, centrals as access points (5th-generation iPod touch pads or iPhone5s) placed in rooms in a concrete building, and a monitor as a server on an iPhone5. The centrals and monitor were connected on a wireless LAN. Each peripheral communicates with a central by BLE, and the centrals communicate with the monitor by sockets on TCP/IP. While individuals with iPhone5s moved around in the building, the "access events" were captured in a few ten-second units at about 10 m from a central. The monitor showed the access events with the peripheral identifier and location, and interactively returned messages to the peripheral. A RTLS was simply created with only iPhone applications using Bluetooth low energy without RFID tags. This system may effectively be used as an indoor RTLS, patient tracking, and calling system.

1 INTRODUCTION

Real-time location systems (RTLSs) are local systems for the identification and tracking of the location of assets in real- or near-real-time (Fisher, 2012; Kamel Boulos, 2012; Lui, 2007). Although as an outdoor RTLS, GPS (global positioning system) has been quite successful, it fails to repeat this success indoors (Kamel Boulos). Hospitals are often large institutions, and personnel often find it difficult to locate portable equipment and individuals when necessary. Although it is hard to believe, this is currently an actual problem.

RTLSs have been implemented and experimented in hospitals to track tagged items and individuals. The systems work by having a hardware tag placed on a piece of equipment or an individual. Tags communicate their locations through a network of sensors that triangulates its position. The data from this network are then mediated by a software interface so that users can see a graphical representation of the locations of all the tags on the network or can search for a particular tag to locate a piece of equipment or an individual (Carrasco, 2010). When staff members require assets, they log onto the system at a workstation or on a mobile device, identify where the closest available item or individual is located, and go and get it or the individual. Hospital RTLSs can be used to improve workflow, increase efficiency, productivity, and staff and patients' satisfaction (Carrasco, Kamel Boulos).

However, the choice of hospital RTLS technology must be made very carefully (Kamel Boulos). Hospital RTLSs incorporate various types of hardware with software interfaces (Fisher). Although sensing a device may employ radiofrequency identification (RFID), Wi-Fi, ultra-wide band, infrared, ZigBee, Bluetooth, or ultrasound, most systems in a surveillance study of hospital RTLSs (Fisher) were RFID based. For degree of accuracy, newer RTLSs offer improved tracking capabilities, yet most of the systems continue to fail at accomplishing room-level accuracy (Fisher).

Bluetooth is the wireless technology standard and has been exchanging data over short distances from fixed and mobile devices, creating personal

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area networks (Heydon, 2012; Lui). Bluetooth has been managed by the Bluetooth Special Interest Group (Bluetooth SIG, 2013) and today exists in many products, such as smartphones, tablets, pads, media players, high definition headsets, watches, etc. Bluetooth is also used in healthcare to real-timely send biomedical data, e.g., heart rate, blood pressure, temperature, electrocardiogram, photoplethysmo-gram, oxygen saturation, energy expenditure, location information, etc. (Kuroda, 2013; Amano, 2012; Lee, 2012; Nakamura, 2012). The data generated in these devices are transmitted to personal computers or other such devices via Bluetooth.

Newer smartphones include “Bluetooth low energy” and move with a tag or an individual. A Bluetooth application could be created on a smartphone/computer without a special hardware device. Then the smartphone could be used as a device tag instead of a special RFID tag of the RTLS. In theory, an application on a smartphone can interactively communicate with an application on a smartphone/personal computer/tablet using the Bluetooth low energy device. Because the Bluetooth low energy protocol is not backward compatible with the previous “Classic Bluetooth” protocol, it is necessary to create/revise applications to capacitate interactive communications.

To our knowledge, there are no studies of hospital RTLSs using smartphones and Bluetooth low energy in the PubMed database. PCs using Bluetooth low energy are not yet commonly used as sensor/beacon networks. Therefore, we have developed an indoor RTLS with interactive communication ability by only using smartphone applications and confirmed the system’s usability in our laboratory rooms instead of on actual hospital wards. We hope that this study will serve as a guide for developers of these types of applications and help identify potential research problems and future products.

2 MATERIALS AND METHODS

2.1 Bluetooth Low Energy

“Classic Bluetooth” was a wireless computer network technology and designed to unite the separate worlds of computing and communications, linking cell phones to laptops. Bluetooth started with Basic Rate with maximum Physical Layer data rate of 1 megabit per second (Heydon). Enhanced Data Rate was added in version 2.0 of Bluetooth to increase the Physical Layer data rates to 3 Mbps. The data rate in version 3.0 of Bluetooth increased up to 54 Mbps. Bluetooth low energy is a subset of version 4.0. However, Bluetooth low energy takes a completely different direction and is intended to provide considerably reduced power consumption instead of increasing the data rate, currently available is 0.3 Mbps. It can keep a connection up for many hours or even days. The transmission distance of Bluetooth low energy is a maximum of 50 m (160 ft).

For programming a communication application with Bluetooth low energy, two users are conceptually assumed: a peripheral and a central (Apple Inc.). The peripheral typically has its own original data that is needed by other users/devices. The central typically uses the data served up by a peripheral to accomplish some task. Peripherals broadcast some of the data they have in form of advertising packets over the air. Centrals can scan for peripherals that they might be interested in. When a central discovers such a peripheral, the central can request to connect with the peripheral and begin exploring and interacting with that peripheral’s data. The peripheral subsequently responds to the central appropriately.

2.2 System Overview

The system is generally made up of three kinds of elements, tags for each item or individual, access points, and a monitor on LAN (Figure 1). For hardware, iPhone5s and/or 5th-generation iPod touch pads are used without any microcomputer in this system. The “peripheral,” “central,” and “monitor” applications were installed in their respective devices. Communication between a peripheral and a central uses Bluetooth low energy. Communication between a central and the monitor uses sockets on TCP/IP with Wi-Fi.

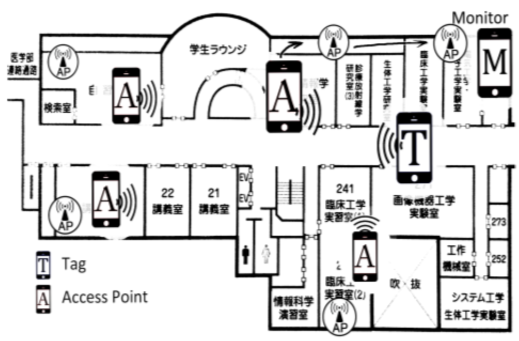

Figure 1: System overview located in our building.

Figure 2 shows communication events and messages between applications. The monitor provides continual service as a server and is always ready to accept any connection requests from any of the system's clients. When the client/central is powered on, it is automatically registered in the monitor.

The peripheral and central search advertising devices (advertise on) every 10 seconds with Bluetooth low energy. When advertising between the devices is established, the advertise turns off (advertise off) and an event "connect" is automatically pops up. These devices exchange messages between themselves such as nickname and UUID defined on the peripheral, ID and location name on the central. The central also sends the connection event to a monitor.

The monitor receives the event and displays the event on a screen with additional information and interactively returns certain responses and/or comments to the particular central and peripheral. When the peripheral moves outside of an access point, an event "disconnect" notice is transmitted to these devices. The peripheral resumes advertising.

2.3 Application on Peripheral, Central and Monitor

Applications for peripheral, central, and monitor provided information, where (access point), when (discovered and disappeared), and who (nickname/asset/nurse, etc.) or what (device ID/data type/data/sensor device, etc.). These applications were delivered from common master source codes with Objective-C, Xcode 4.6.2, on a Mac Mini (CPU Intel Core i7, 4GB, 1600M Hz, DDR3, OS X 10.8.4, Apple).

The most important parts were communication routines for Bluetooth and sockets on TCP/IP. The Core Bluetooth framework handles low-level details from the Bluetooth 4.0 specification. In the central/client application, classes, and the methods used were: `CBPeripheralManager`, `updateValue`, `CBCentralManager`, `scanForPeripheralsWithService`, `CBPeripheral`,`write`, `read`, etc. for Bluetooth, and `NSNetService`, `NSFileHandle`, `NSNetSeriviceBrowser`, `NSNetService`, `write`, etc. for sockets (Figure 3). A class `NSnotificationCenter` bidirectionally transmits events and data between a central class and client class. The peripheral and monitor applications were subsets of the central/client application.

Because Bluetooth low energy was designed to send a small amount of data, up to 20 bytes at once, the transmission routines were devised to send/receive long string messages. Errors that occurred while handling the smartphones were the unintentional pressing of functions on the touch screen in pockets or bags, which was solved by the use of double taps (Neubert, 2010).

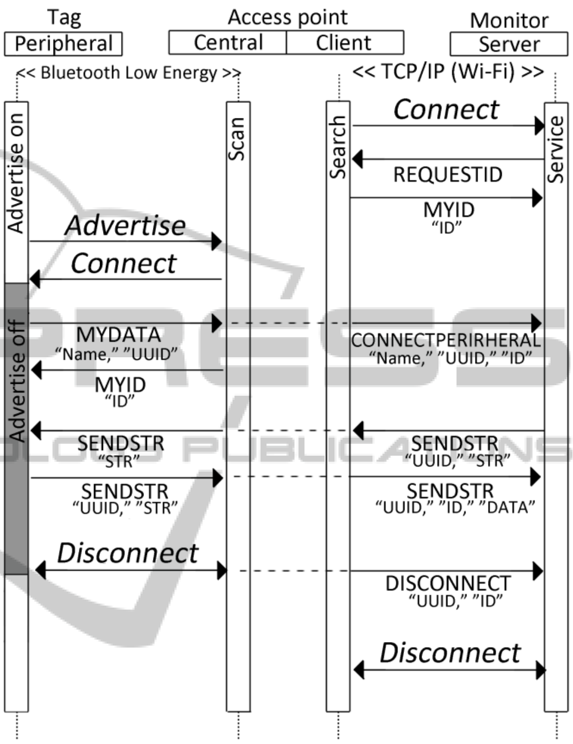

Figure 2: Simplified sequence.

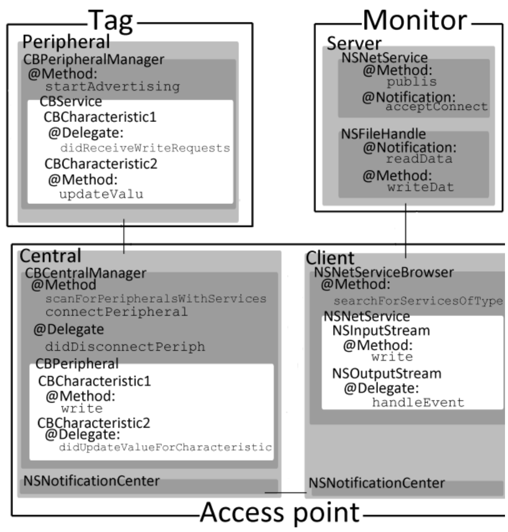

Figure 3: Application overview.

3 STATUS REPORT

The system was evaluated in a concrete building instead of hospital wards (Figure 1). Applications for centrals, as access points, were installed in iPhone5s and 5th-generation iPod touch pads. These devices were positioned on the second floor at a lounge and the Medical Informatics, Biomedical Engineering, and Clinical Engineering laboratory rooms. The distances between these access points were each about 30 m in a direct line of sight. A person with an iPhone5 installed with a peripheral walked around in the building. During the test walk, the access events and response messages were displayed on the smartphones and they were captured in ten-second units.

Figure 4 shows a captured screen of the monitor. A textbox on the top of the screen was used to set the user's own ID and to send a message, ex. "Hello," to a peripheral with the button, "Send Data." The message, "Hello," was shown in peripheral screen below. When the monitor got a request to connect from a certain client, the monitor responded, "I request your ID," to each client at any time. In this case, three "location IDs" were received sequentially: "Biomedical Engineering Lab," "Medical Informatics Lab," and "Lounge." The corresponding messages were displayed on the last two lines of the monitor screen, "Nicary in Lounge" and "Nicary left Lounge."

Figure 5 is a screen shot of an access point with the ID, "Lounge." A status bar on the top shows active icons of Wi-Fi on the left side and Bluetooth on the right side. The upper area of the screen was for a client, and the lower area was for a central. The client area showed the connection sequences, such as "Search," "Discovered," and "Connect to the monitor with TCP/IP in the local domain." The last three lines showed the access events that were sent to the monitor, "Connected peripheral" and "Disconnect." The peripheral area showed connection sequences in the central, such as "Discovered peripheral," "Connected," "Discovered," "Received MYDATA," "Send myID and Lounge," etc.

Figure 6 shows a screen of the peripheral with ID, "Nicary," set on the top textbox. The second box and the button were used to send a message to the monitor. The peripheral was found by a central at, "Biomedical Engineering Lab," indicating that an

Figure 4: Captured screen of monitor.

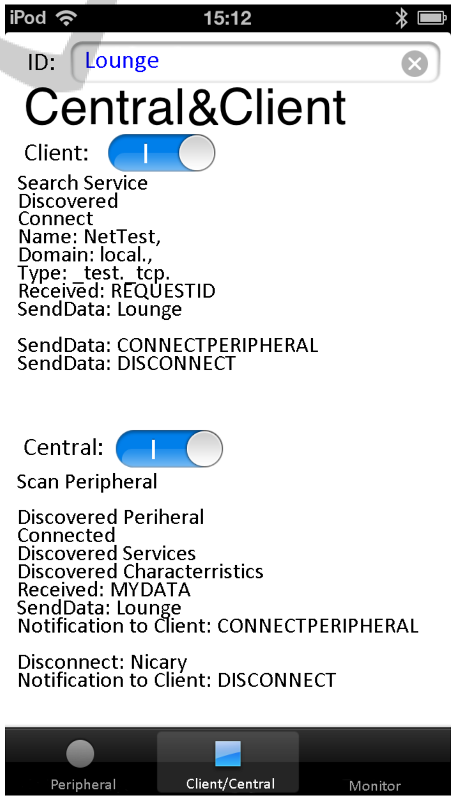

Figure 5: Captured screen of central/client.

asset being tested might be near there or in the Biomedical Engineering laboratory. The peripheral moved out from the access point to "Medical Informatics" with a message, "Hello," from the monitor and returned a message, "Hi!" It got to the lounge.

The operating time of the peripheral device is bound to the battery life of the smartphone. The power consumption of Bluetooth low energy is not defined in the Bluetooth specifications. The battery level can be monitored in units of 5% with certain APIs. The battery level during the use of the application on a peripheral was measured hourly for about 6 h. The results were compared with the control in which an application was not used. The battery levels in use and under control declined linearly from 100% to 15% of the power over a 5-h period (Figure 7). There were no significant differences. There were no data under 10% because of the compulsorily smartphone shut down at battery levels of 10% or lower.

4 DISCUSSION

An RTLS could be constructed simply with only smartphones without PCs, RFID tags, and their sensor network. Three kinds of applications worked well as an RTLS with a few devices. Although peripheral, central and monitor applications could be designed to communicate with two or more devices, we should confirm how many devises could operate completely as one system.

RTLSs are usually evaluated for accuracy, however, the accuracy should be considered according to the requirements of the system (Lui). We assumed a room-level accuracy. The transmission distance of Bluetooth low energy is approximately 50 m but insufficient for indoor RTLSs. However, the distances to locate assets can roughly be controlled by monitoring the RSSI (Received Signal Strength Indicator) in an application. In the present study, the distance was set at approximately 10 m in a direct line of sight. That might be adequate to locate individuals and other assets such as respirators and intravenous pumps in a hospital. The battery level was kept for 5h with Bluretooth low energy, in which means that the application can be used for a few hours during hospital stays for outpatients.

There are no Bluetooth low energy beacons or sensor networks in hospitals yet. Because the access point devices, smartphones, were placed on desks in the present study, the system lacks the reality of an actual hospital setting. If an application with Bluetooth low energy like our central/client was installed in the in the hospital PCs currently in use, they could all function as Bluetooth low energy beacons without any other additional devices.

Current health monitoring devices with Bluetooth low energy are used to automatically collect data from their system's devices and send data to their servers on the Internet (Lee, Neubert). However, thedevices cannot find the asset "locations" because there are no access points in any of the

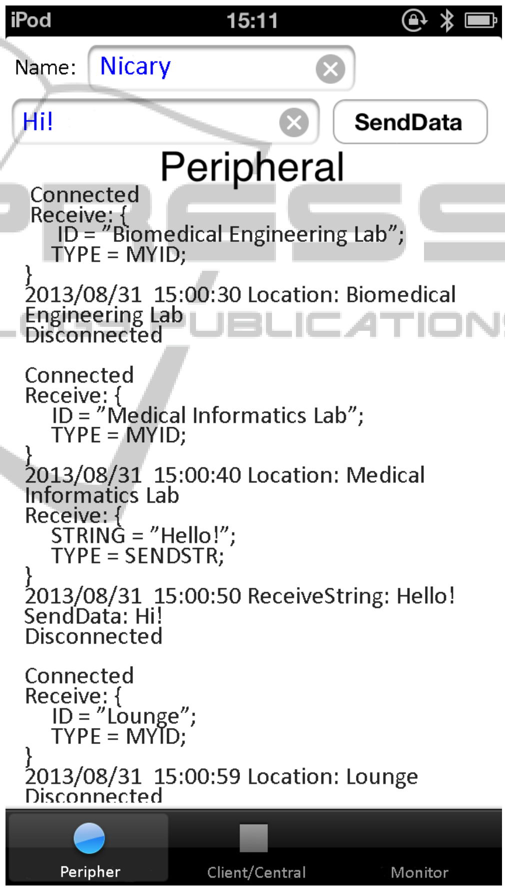

Figure 6: Captured screen of peripheral.

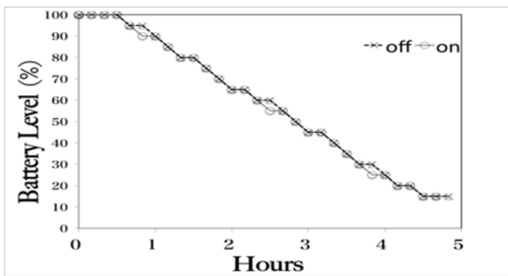

Figure 7: The battery levels were measured hourly in use and no use of the application.

rooms. When such devices can automatically access beacons, these "locations" will become important additional information, e.g., "Sports club" or "Massage room," or in the case of monitoring heart rate and body temperature, e.g., "Sauna," "Pool," "Day room," or "Greenhouse." This relatively simple technology will be common in hospitals world wide in the next few years.

In future works, two computer applications for the access point and the monitor will be developed and implemented on Mac usually working in rooms to function as fix access points instead of personal iPhones.

5 CONCLUSIONS

A RTLS was simply created with smartphones installing applications using Bluetooth low energy without RFID tags and its sensor network.

DISCLOSURE STATEMENT

The authors declare no conflict of interest.

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