DESIGN AND DEVELOPMENT OF DUAL RADIO EMBEDDED SOFTWARE APPLICATION STACK FOR WIRELESS MESH NETWORK BASED IOT SYSTEM

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Name : Dr. Kim Lim Chuan

Date : 6/6/2017

Dedicated to

My mother

Normiza binti Hashim

My supervisor

Dr Lim Kim Chuan

Co-supervisor

Dr Soo Yew Guan

And those people who have guided and inspired me throughout my journey of education

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ABSTRACT

This project involves discovering how the emergency exit signboard, commonly available at every exit of retail shops and shopping mall, is proposed to allow indoor localization either for targeted push advertisement or victim stuck in the collapse building. An emergency exit signboard, made up of a metal and incandescent light bulb with a battery-backup system, is used in public facilities to denote the location of closest emergency exit. The proposed system consists of massively deployed ENDLS nodes connected to each other using self-healing Wi-Fi mesh network where the iBeacon broadcasted by the user smartphone app will be picked up and pushed to the cloud to help to localize the user. The iBeacon sniffer of the developed ENDLS node can confidently localize the position of the user with up to 3 meters (average -86.4±1.3 RSSI value) which is accurate enough for the targeted pushed advertisement. The constructed self-healing Wi-Fi mesh is tested and can successfully carry packet with transfer rate of 6Kbytes/s (30bytes per packet, 5ms interval) to server computer without any loss. In the event of power outages by disaster, the battery can continue to supply power to the developed ENDLS nodes. The designed and developed emergency server gateway computer, connected with the deployed ENDLS nodes, is able to display the vital signal broadcasted by the victim' wearable on the rescue portal.

ABSTRAK

Projek ini melibatkan penemuan bagaimana lampu keluar kecemasan yang biasanya dipasang pada setiap pintu keluar kedai dan pasaraya boleh digunakan untuk pencarian tempat dalam banggunan sama ada untuk periklanan atau menentukan kedudukan mangsa yang terperangkap dalam baggunan yang runtuh. Lampu keluar kecemasan dibina daripada lampu dan mempunyai bateri yang digunakan untuk menujukkan lokasi pitu kecemasan terdekat. Sistem yang dicadankan mempunyai pemasangan nod ENDLS secara besar-besaran yang bersambung antara satu sama lain dengan mengunakan *self-healing mesh network* dimana iBeacon yang telah disiarkan oleh aplikasi telefon bimbit pengguna akan di tangkap dan dihantar ke *cloud server* untuk menetukan kedudukan pengguna. iBeacon *sniffer* yang terdapat pada nod ENDLS boleh menetukan posisi pengguna dalam jarak sehingga 3 meter (purata -86.4±1.3 nilai RSSI) dimana sudah cukup tepat untuk penghantaran iklan. *self-healing mesh network* telah diuji dapat menghantar paket dengan kadar kelajuan 6Kbait/s (30bait per paket, 5ms interval) kepada komputer server tanpa kehilangan data. Ketika berlanya ganguan bekalan kuasa oleh kemalangan, nod ENDLS akan terus hidup dengan bekalan kuasa oleh bateri. Komputer *server gateway* kecemasan yang telah dibina akan bersambung denga nod ENDLS dan boleh mampamerkan insyarat signal yang telah disiarkan oleh peranti mangsa pada portal penyelamat.

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SSID	- Service Set Identifier
UUID	- Universally unique identifier
RSSI	- Received signal strength indication
BLE	- Bluetooth Low Energy
UART	- Universal asynchronous receiver/transmitter
BBB	- BeagleBone Black
ENDLS	- Emergency Navigation Disaster Localization System

CHAPTER I

INTRODUCTION

Indoor navigation has been an interesting problem for a long time and a lot of people were still doing research on the topic. The aim of this thesis is to implement a demo application on an BLE-enabled Android phone using only its own hardware together with an indoor map to navigate indoor.

1.1 Background

The introduction of the Global Positioning System (GPS) made outdoor navigation with high precision possible. Today it is widely used in automobiles, aircraft and watercraft. This precision decreases dramatically when the receiver is placed indoors or close to objects reflecting the GPS signal making indoor navigation difficult. Accurate positioning indoors could be used for anything from aiding firefighters or to finding a desired shop in a large supermarket. Since the GPS does not give an accurate enough signal indoor, other techniques like iBeacon could be used to replace the GPS signal.

When you visit any shopping complex, factory, office or any building, it is not hard to discover that the emergency signboard appears at almost every emergency exit. This follows the OSHA requirement that "each exit route must be adequately lighted so that an employee with normal vision can see along the exit route" [1]. Most of

KELUAR signboard is implemented with a backup battery to keep light-up when there is a power failure.

Instead of just being a board to denote the location of closest emergency exit, its backup battery system should allow it to serve more functions in a critical situation. The concept of our project is to utilize its backup battery power to work with our Emergency Navigation Disaster Localization System (ENDLS).

1.2 Objective

The aim of this project is;

a) Utilize the backup battery storage of LED exit lighting for IoT device
b) Develop dual radio (Bluetooth and Wi-Fi) embedded software application
c) Provide a smart phone application to identify indoor location

1.3 Scope

To achieve the project objective, several scopes of the project had been highlighted;

a) Wireless Mesh nodes connect each other whenever any other node is nearby
b) ENDLS can get the approximate location of the active Bluetooth devices
c) System runs based on directly supplied power and battery life that implement on KELUAR sign when blackout happens
d) Indoor localisation requires internet connection to works

1.4 Project Structure

The main component of the project can be device into three main parts which is;

a) Smart Devices – Any Bluetooth-enabled smart device such as mobile phone, smartwatch, tablet, etc.
b) ENDLS Nodes – KELUAR sign that implemented with ESP8266 WiFi device and nRF51 Bluetooth device.

c) Server – Processing device which computer and BeagleBone Black and database using Firebase and MySQL that used in this project

1.5 Problem Statement

iBeacon device has been used for indoor navigation which means it has been installed in large number of units in one building but it is battery powered. After a few periods, battery replacement is required for all units. Therefore, replacing battery powered IoT nodes is troublesome.

When enter a big shopping complex like IOI city, Mid-Valley, people tend to get lost inside the building. It's even hard to identify nearest lift or stairs, toilet, shops, information centre and even my current location.

Current building design, there is no facility that can help rescue locate the victim in case of any disaster happens. And it is inefficient in identifying the victim who trapped inside the building.

1.6 Thesis Outline

Chapter 1 will give the briefing introduction to the project. Here will state the project objective, project scope, project structure, problem statement and the design of the project.

An extensive literature review has been done in chapter 2 to accomplish this project. The purpose of the literature study is to get a clear idea on the system and to learn about the technologies that can be used to design such a system. Some part of the literatures were scientific articles from IEEExplore, ProQuest and ACM Digital library. Existing commercial systems were also tested and reviewed as much as possible. The proposed system is based on iBeacon technology and Wireless Mesh Networks and therefore it is necessary to understand this technology in depth.

In chapter 3, potential techniques and technologies were identified from the literature study and practical observations and demonstration. Later these techniques and technologies were combined to come up together with a solution design and a prototype is developed.

After the prototype of the system is developed then it is necessary to test the system and evaluate its performance. In chapter 4, the test results were analysed and necessary modifications were taken into consideration to further improve the system. Thesis is ended at chapter 5 with the project conclusion and some proposed future work to improve this project.

CHAPTER II

LITERATURE REVIEW

This chapter first introduces Bluetooth technology, wireless mesh network and then explains why and how a system for ENDLS users should be designed. Following is a review of existing indoor positioning techniques. By compared them and then justify the decision to implement a beacon-based location system.

2.1 The Bluetooth Low Energy technology

Figure 2.1 – Bluetooth Logo

Bluetooth technology is a standard enabling wireless connectivity of devices and operates in the unlicensed industrial, scientific, and medical (ISM) band at 2.4 to 2.485 GHz [2]. BLE was introduced as a part of Bluetooth 4.0, released in 2010. Although previous versions of Bluetooth were widely supported on a wide range of devices, Bluetooth 4.0 is not backwards compatible. This low energy consumption is achieved as no paired connection is required between two BLE devices when one is transmitting frames and the other receiving them [3].

BLE features two communication modes: advertising and data channel. The iBeacon technology only utilizes the advertising mechanism while other services that require bidirectional communication utilizes both modes; advertising for discovery and data channel for communication between the connected BLE devices. [4] As the iBeacon were the one of the focus of this project, detailed information about the BLE two-way communication mode is not included.

A BLE beacon typically broadcasts at a certain interval frames that contain a unique identifier. Tadlys Wireless Communications Ltd.'s TOPAZ is one of the example of commercial indoor positioning system that claims an average positioning accuracy of 2-3 meter, can locate tens of tags simultaneously, and covering areas of thousands of square meters [5].

2.1.1 Beacon and iBeacon

Figure 2.2 – iBeacon logo by Apple Inc.

Beacons are basically any transmitting devices that transmit radio signal at some interval. Bluetooth beacons typically use low energy Bluetooth also known as BLE (Bluetooth Low Energy). BLE is a short-range radio technology which is optimized for ultra-low power consumption [6]. Bluetooth beacons broadcasting these BLE signal can be discovered by smart devices such as smartphones or tablets residing within the signal's range. These beacons are powered by batteries having a typical battery life from 6 months to 2 years or by a fixed power source [7].

iBeacon is Apple's trademark, introduced in mid-2013, that refers to protocols devices and uses of BLE to create user experience. Apple must certify each vendor that wants to carry the iBeacon name, which means, the vendor has access to Apple's

trademark and their beacons are configured to work well with the Apple devices. This however does not pose any restriction for the iBeacon to be used by Android or other devices [8].

2.1.2 Indoor Path Loss

Practically a beacon's range is affected by obstacles such as walls, furniture or people around it. These can weaken a beacon's signal, which is why the measured distance is a rough estimate rather than an accurate value. These obstacles result in signal path loss.

Path loss (or path attenuation) is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through space. In BLE Beacons this path loss happens due to several factors such as increasing distance between the transmitter and the receiver. Beside this, another reason for signal loss is multipath propagation which comprises the factors like reflection, diffraction and scattering of signal [9].

Signal interference is also another major reason for uneven RSSI values and is likely caused by other transmitters and barriers [10]. BLE operates in the 2.4 GHz channel band which is the same channel band with Wi-Fi. Apple has done its own research and identified some materials that can cause interference [11] as shown in Table 2.1.

Table 2.1 – Bluetooth interferences material

Type of obstacle	**Interference Potential**
Metal	Very High
Concrete, Rocks	High
Wood, Plastic	Low

2.1.3 iBeacon Advertising Packet

iBeacon uses the BLE advertising packet to transmit data about its identifier. The data is embedded in the BLE's packet as shown in Figure 2.3.

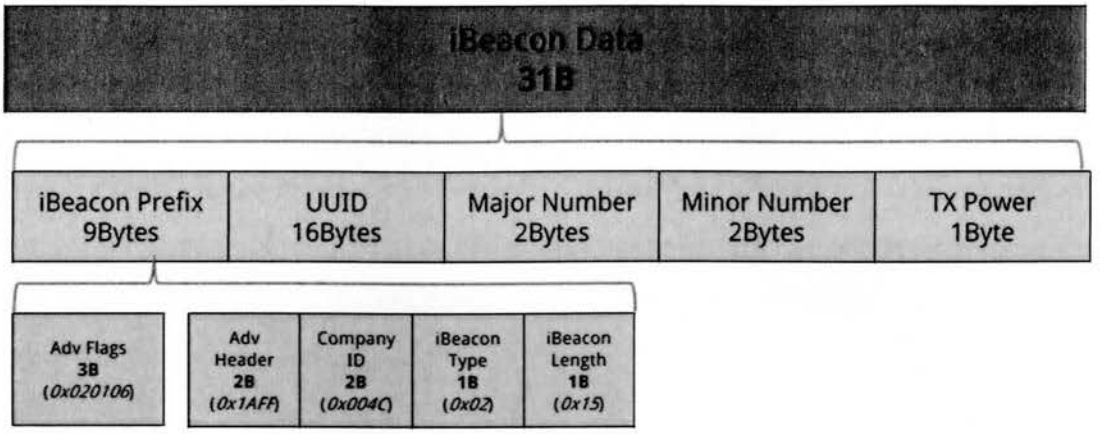

Figure 2.3 – iBeacon Data

The description of the field in iBeacon advertisement data is summarise in table 2.2

Table 2.2 – Description of iBeacon data fields

Field	**Size**	**Description**
iBeacon Prefix	9 bytes	Stores flags, header, company ID, type and length
UUID	16 bytes	Contains the Proximity UUID(Universal Unique identifier), identical for all the beacons owned by the same organization
Major	2 bytes	Use to group the beacons into some kind of logical area.
Minor	2 bytes	Further grouping and sequential ordering of the beacons
Tx Power	1 bytes	Stores Tx power rate

Along with the signal transmitted from iBeacon, a packet of data is sent. This packet, often referred as advertisement packet broadcasted periodically by the iBeacon, typically containing information about who they are and where they are. Basic information provided by beacon are UUID, Major and Minor.

A scanning application reads the UUID, major number and minor number and references them with database to get information about the beacon; the beacon itself carries no descriptive information. The TX power field is used with the measured signal strength to determine how far away the beacon is from the smart device [12].