Enhancing energy efficiency in HVAC with RFID technology based occupancy detection solution

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A thesis submitted to

Auckland University of Technology

Master of Computer and Information Science (MCIS)

2015

School of computer and mathematical science

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Table of contents

Abstract

Over the years, the concept of smart buildings or intelligent buildings has been discussed and revealed as an effective solution to reduce the energy consumption of residential and commercial buildings without any impact on occupants' thermal comfort. To optimize the building operation, the exact location of occupants inside buildings should be identified and devices such as RFID sensors used as an effective solution to increase the accuracy of an occupancy detection system. Until now, I have not find specific energy efficient solutions for heating or energy consumption but in this research I propose an accurate and power efficient approach to detect the occupants in an open office and a training room using mobile devices to send signals. This approach may experience the *occupancy detection problem* but resolves it by exploiting iBeacon which is a low-power technology. Along with the iBeacon technology, Bluetooth low energy (BLE) technology is used as it presents a very power efficient technology. iBeacon technology with BLE is a good solution for occupancy detection in buildings because of its higher level of compatibility and accurate detection.

List of figures

List of tables

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Sincerely

Joseph Suk

Chapter 1 Introduction

1.1 Current model/situation

Sensors and actuators are advancing a new breed of smart buildings or intelligent buildings that are better energy efficiency of the building and thermal comfort of the occupants in the building. Over the years, the number of studies investigating “How smart buildings can be made cheaper and greener” have increased and researchers have made more effort to acquire better intelligence. In this context, one well-known approach for the smart building is the method of direct interaction between the occupants and the smart building by specifying their personal rules. In this case, fundamentally two factors are needed to understand the intelligence of a building –

- Identifying who are occupants and,
- Retrieving occupants’ exact location within the building
- Figuring out the number of people in the building or office which can impact the overall energy consumption of the whole building

Understanding the exact number of occupants and the occupants’ position within the office interactively and deeply influence both the energy efficiency and level of thermal comfort of a building. However there is a well-known challenging problems of occupancy detection when retrieving the location of occupants within an office. In my research, I propose an Internet of Things (IoT) based occupancy detection system to solve *the problems of occupancy detection.* The proposed system is based on iBeacon technology and IoT technology. These are two interrelated solutions that solve the above defined problem, even though one is primarily invented to enable the definition of indoor proximity systems. Most importantly, the iBeacon technology enables a device to make extremely precise determination of what is nearby and even enable a determination within centimetres. Secondly; new types or any type of application can be created by incorporating the high-precision location information into an application because the information is quickly available. Taking into account these two reasons, the proposed detection system provides an

- Ability to detect the number of occupants in the test office

- Ability to identify and track occupants by gathering information of occupants' movement

Bluetooth Low Energy (BLE) or Bluetooth Smart is an enhancement of the existing Bluetooth specification as it reduces classic Bluetooth's peak, average, and idle mode power consumption to achieve lower-powered operation [1]. Accordingly the proximity specification in BLE is the key technology for enabling the iBeacon. iBeacon which is built on BLE can bring power efficiency advantages. Many proximity applications or devices require battery operation to trigger within a target area, but iBeacon can operate for extended periods of time on battery power only. Furthermore, the proposed technologies do not require Internet access to be embedded within an application. This also brings benefits.

1.2 Test site

1.2.1 Building location

Location of tested site is Level 5, Hana Daetoo Securities Bldg., 82, Uisadan-daero, Yeongdeungpo-gu, Seoul, 150-705, Korea. Summary of property features are as below.

Gross floor area	69,826 square meter
Total floors	23F / B5
Built	Year 1994
Target floor (5F)	**Gross 1,470 square meter**

Hana-Daetoo Securities Building is adjacent to Yeouido Station and located in the Finance District.

1.2.2 Building service

A central HVAC plant provides air-conditioning and heating throughout the building via concealed ceiling mounted ducts. The HVAC system is described as a dual duct high velocity system, incorporating mixing boxes, refrigeration and heating plant, with associated control functions. This methodology of supplying air conditioning to the building using a dual duct system has by comparison a high energy consumption to that of more modern, large floor plan type buildings using other types of plant.

1.2.3 Test office

The field test needed to evaluate the technical feasibility and reliability of integrating occupancy detection solutions with HVAC operations. From the field tests, an efficient algorithm to detect occupants in thermal zones would be proposed to reduce energy consumption in HVAC operation. This field test was carried out on one of the floors (Level 5) of the commercial office building. The test office was selected based on its space and functionality as the tests are focused on detecting occupants for the purpose of reducing energy consumption.

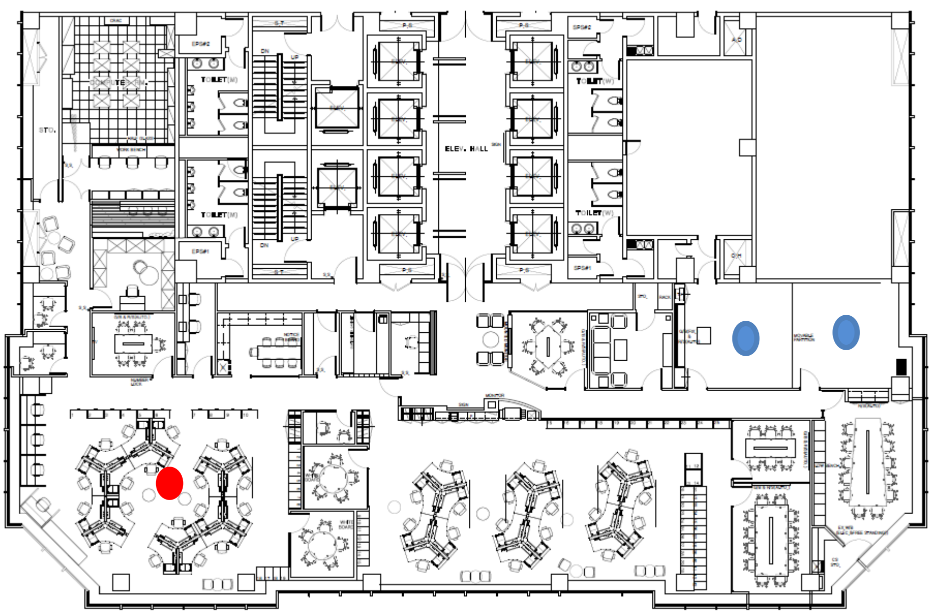

Figure 1. Test floor layout with *HVAC zone* division

1.2.4 Office environment

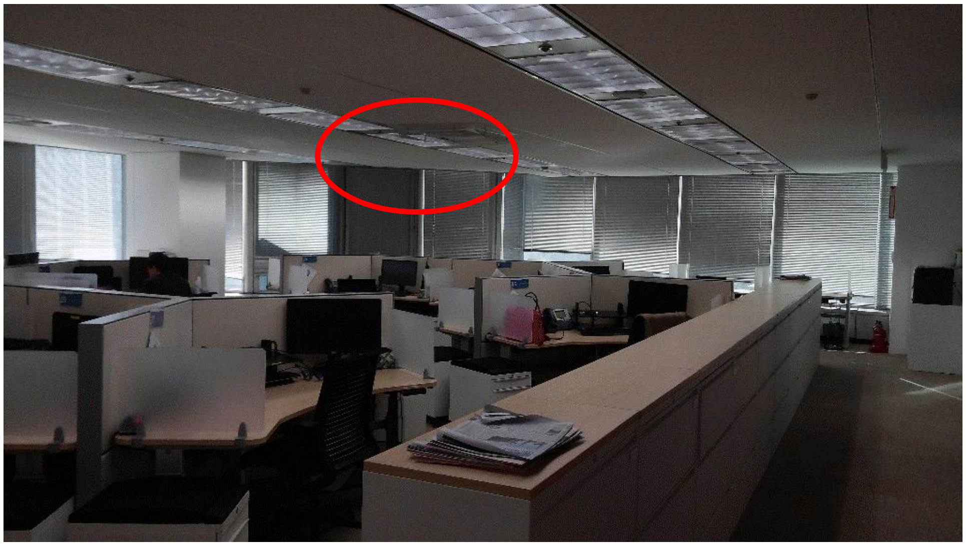

Figure 2. 1st Test floor (Open office area and red spot from Figure 1)

Figure 3. 2nd Test floor (Training room and blue spot from Figure 1)

Currently Samsung's 4Way Cassette units are fitted in the test Office and Training Room ceiling. The 4Way Cassette provides conditioned air flows into the office and training room via four air outlets.

Figure 4. Samsung NS1404DXEA for tested office

Features	**Type**	4 Way Cassette S
Model Name	**Indoor Unit**	NS1404DXEA
Capacity	**Cooling [kW]**	3.50/14.00/15.50
	Cooling [Btu/h]	11,900/47,800/52,900
	Heating [kW]	3.50/16.00/18.00
	Heating [Btu/h]	11,900/54,600/61,400

The 4 Way Cassette units are installed because (1) the building HVAC system has a centralized control system and operation is fixed and (2) the centralized building HVAC is running according to policies and government regulation without any consideration of the occupants' actual usage. Currently installed Samsung 4Way Cassette units provide conditioned air flow into the office and meeting room via four air outlets to meet occupants' satisfaction.

1.3 Research motivation, objective and prior research

The Internet of Things (IOT) is taking shape now and major global IT companies are committed to connect things to the cloud, integrate with existing infrastructure, and manage big data. The objective of this research is to investigate current use of the Internet of Things (IOT), identify the trends of these technologies and design simple, smart building concepts with Internet of Things technologies. Owners or operators (property managers) of any type of building from small to medium sized buildings are now able to realise the importance of energy savings along with other benefits from building automation. Solutions for energy savings are varied but are a necessary investment. They can however, prove to be a large financial commitment for owners. The cost of using the Internet of Things (IoT) technologies is relatively cheaper and simple implementation can bring comprehensive benefits. This work is mainly inspired from the work done by Giorgio C, Massimo D M, Alessandro A. N, Vincezo R. and Donatella S. [2]. This work has summarized the IoT technologies especially Beacon technology used both in current real world situations and in building management systems.

1.4 Research question, hypothesis and thesis structure

To achieve the research objective stated in section 2.5, I have one research question which will need to be answered in the course of this research.

<u>CAN RFID BASED OCCUPANCY DETECTION SUPPORT REDUCING ENERGY CONSUMPTION OF THE HVAC SYSTEMS?</u>

In order to answer the above research question, the thesis specifically considers the following sub-questions;

- How does occupancy information affect the energy efficient operation of building HVAC systems?
- Is it technically feasible and reliable to utilize RFID technology to detect and track occupants in HVAC zones?
- Can temperate segregations in open offices support energy saving if coupled with occupancy detection?

This will lead us to make the following hypothesis during the entire research period.

- One of the RFID technologies, iBeacon, can readily detect occupants’ activities.

Chapter 2 provides a literature overview of previous studies of current state of the art smart buildings, especially those that utilise HVAC systems. This chapter includes a brief overview of the RFID technologies including Internet of Things and discusses the use of the RFID technologies in the area of HVAC systems.

Chapter 3 discusses the research questions in detail and justifies the methodology being used in the thesis. Research design, iBeacon protocol and data collection/analysis.

Chapter 4 describes the iBeacon modification model and the methods of the proposed approach.

Chapter 5 reviews the experiments and evaluations for iBeacon protocol. Data collection procedure and data analysis is included.

Chapter 6 summarises the entire research and discusses any findings. Limitations and problems are reviewed.

Future work which includes both short and long term plans and ideas being considered to solve detection problems will be discussed.

Chapter 2 Literature review

This chapter provides a review of relevant literature that reports research findings related to the current state of the art smart building systems (especially HVAC systems), models, and their particularities. It also reviews new technologies and concepts of Internet of Things technologies in terms of energy savings. This section describes how new technologies and concepts can help to improve HVAC energy efficiency and reduce energy consumption. Section 2.1 presents problems in current HVAC systems that lead to inefficiency of energy consumption. It also reviews the types and causes of how a sensor platform can be used for accurate occupancy detection in a commercial office. Section 2.2 provides an overview of the Internet of Things with RFID technology. Section 2.3 describes how the Internet of Things with RFID can help to improve accuracy of occupancy detection and Section 2.4 discusses the use of the Internet of Things in the area of HVAC systems. Finally, section 2.5 outlines the data analysis method adopted for the analysis of data obtained from the building simulation experiments.

2.1 Current situation of HVAC systems

There is much relevant literature that reflects the many different approaches for reducing energy consumption in HVAC systems.

Occupancy patterns management

Occupancy and occupant behaviour are the most significant drivers of HVAC system management. Sensors are required to gather real-time data from occupancy and occupant behaviour as inference detection [3, 4, 5, and 6]. Normally Bayesian inference techniques can provide predictions of the occupant behaviours as a mode of inference detection. In [7] authors identified the problem of user behaviour prediction in a home automation system. This paper proposes that anticipating the energy needed for a service is based on the prediction of possible inhabitant service requests. The relied method is Bayesian networks to predict and diagnose the users’ behaviour. In [8], they develop a prototype control system in an actual residence for air heating, lighting, ventilation, and water heating by observing the lifestyle and needs of the occupants. Neural Networks is used to model the occupant's behaviour and their needs, [9] proposed an AIM project in which authors create user profiles from the users' behaviour by prediction algorithm that extracts features from the users' habits in the form of probability distributions. Based on user profiles and real-time information provided by the system, user behaviour can be predicted and the energy consumption can also be optimized by being controlled automatically. In Erickson [10], authors used Markov chain (MC), Closet distance Markov Chain (CDMC) and Blended Markov Chain (BMC) to propose a statistical model of the temporal occupancy of a building for predicting user mobility patterns. Data is collected from a sensor network and with this collected data and the OBSERVE predictive demand control strategy, the authors tested the energy savings and air conditioning performance. From the experiment results, we learn lessons as follows 1) Real time occupancy data is critical, 2) Predictive strategies show better energy savings and 3) Actual level of occupancy must be identified to optimize ventilation levels.

In another paper [11] of Erickson et al., to build user mobility patterns, an agent-based model is proposed. Agent-based model (ABM) is used for simulating mobility patterns to develop HVAC control strategies. The multi Agent System [12] implemented decision trees to make decision under uncertainty in the buildings. The ISL (incremental synchronous learning) system is a core part of the agent and uses fuzzy-logic which is able to predict the user's needs.

iDorm [13] is a test bed for intelligent-learning and adapted mechanism to apply to ubiquitous computing environments. This agent measures various activities such as, sleeping, working and entertaining etc. One approach for measuring technology which directly infers the behaviour of the occupants is from the previous study of a user entry-exit logs of the building security system [14]. The authors presented a prototype system which can monitor energy consumption by proximity sensors being used by each individual [15].

However another thesis identified that the building itself features an ultrasonic location system based on 3D location system. The 3D location system is equipped with the principle of triangulation and relies on multiple ultrasonic receivers embedded in the ceiling [16]. This location system provides a three (3)-dimensional tracking solution. I can conclude that wireless sensor networks (WSNs) will be a very necessary part of monitoring building energy consumption. The wireless sensor network system can bring great benefits for gathering user behaviour information or any patterns and its interaction with appliances from the commercial office environment. WSNs are regarded as one promising technology for decreasing energy consumption because of their low-cost and easy-to-deploy sensor networks in many references.

Weather forecasts predictions

There is another main method to improve energy efficiency; weather predictive control strategy. From various references, I see that a predictive strategy as a means of improving the energy efficiency is both an efficient and promising strategy, rather than real-time weather data in thermal control of buildings [17, 18, 19, 20 and 21]. In the reference [22], Authors presented a number of sophisticated control strategies for a solar domestic hot water system – especially a “certainty-equivalence controller” which uses weather forecasts or weather statistics, and a controller which is based on stochastic version of the dynamic programing algorithm. The design of these strategies is founded on probability distributions which were based on a priori weather data. From the presented results, lower energy costs can be achieved with some predictive control strategies.

To prove the energy efficiency of an intermittently heated radiant floor heating system, a predictive control strategy based on forecasting model of outdoor air temperature is explored [23]. The predictive control strategy uses decisions which are based on the past experience used in the conventional intermittent control technique. The experimental results reveal that use of the predictive control strategy can save energy during specific time periods.

Short-term weather forecast models are introduced in past research [24] and explored with respect to their forecasting accuracy in the control of thermal energy storage systems. From the investigation the predictive optimal control of active and passive building thermal storage inventory is a highly capable control when weather forecasts are perfectly correct. The implementation of a model-based predictive control program was carried out and the predicted variables for the implementation were ambient air dry-bulb temperature, relative humidity, global solar radiation, and direct normal solar radiation. Analysis of a real-time optimal control test was conducted for a very short time period and it was shown that energy consumption was reduced and cost also reduced significantly for the test period.

In weather forecast predictions methods [25, 26, 27 and 28], uncertainty or inaccuracy of the predictions is a problem for which there is currently no solution. A Stochastic predictive control (SMPC) algorithm was proposed to solve the complication made by uncertainties [29]. Another investigation [30] uses a Model Predictive Control and weather prediction to increase the energy efficiency. Applied strategy for climate control takes into account the uncertainty of weather predictions. Similar with Oldewurtel's strategy, Ma, Y. and Boreelli, F [31] also presents a nonlinear stochastic predictive control method to reduce the probability of thermal discomfort. Stochastic Model Predictive Control algorithm is also considered - using true data through the use of copulas to reduce uncertainty [32].

2.2 Internet of Things application field

Much research is presented on IoT (the Internet of Things) relating to various technologies and various fields. Furthermore, major global companies e.g. Microsoft, Oracle, Intel etc. are focused on the IoT field with big data. I discuss this research and technology trends below.

IoT and the automotive industry transform the car ownership experience

Consumers or car owners want the digital experience in their vehicles to align with other day to day digital experiences. Once implemented to the IoT, the car integrates with interdependent web of information flow. By integration, any data turns into actionable awareness. Any technical challenges of implementing the tied vehicle BMW's Navigation system connectedDrive uses embedded computers responsible for monitoring and control of vehicle systems, for example, telematics, infotainment, connectivity and Advanced Driver Assistance Systems [33]. Mobile Interior imaging, or project mobii explores how interior-facing cameras are integrated with sensor technology as IoT technology. This research project is conducted by both Ford and Intel to create a more personalized interaction between driver and vehicle by using data generated within and around the vehicle [34]. Joint research for Toyota Motor Corporation was focused on developing user interaction methodologies, especially by touch, gesture and voice technologies which enable new usage modes for mobile device connectivity in the vehicle [35]. DENSO's research on developing the next generation of in-vehicle information systems is bringing substantial benefit to drivers via IoT technologies. Drivers or any other occupants in a vehicle are able to access information both from the vehicle itself and various personal devices e.g. mobile phone and tablet etc., through next-generation in-vehicle information and communication systems [36].

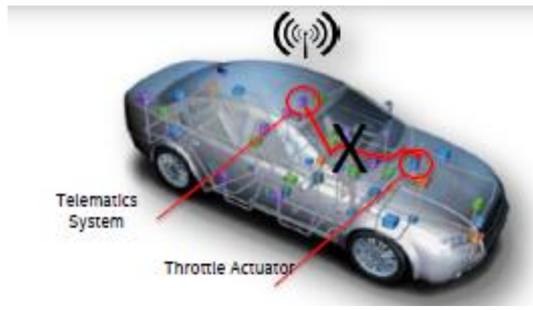

Figure 5. Secure my connected car [33]

IoT offers truly personalized medicine

With powerful IoT technologies, personalized medicine and analytics in Health and life sciences are possible and even optimize treatment and health care delivery. IoT technology can accelerate Genome analysis as it can fulfil demand on genome sequencing demanding higher performance computing (HPC) clusters for analysing [37].

There are approaches to Big Data relating to IoT technology advances in healthcare. As per the figure below, telemedicine integrates medicine and healthcare devices including manometers, thermometers, and blood sugar meters. Those devices are currently widely used in ordinary households, and are necessary devices for health maintenance and disease management. Data streams from such heath care devices contribute to the remarkable improvement in data volumes [38].

Figure 6. Telemedicine Devices for satellite clinics [39]

As IoT-based smart rehabilitation systems can provide better solutions for mitigating problems associated with aging populations and shortage of health professionals. Fan et al. [40] presented an ontology-based automating design methodology (ADM) for this requirement. Authors recommend ontology as this can aid understanding the symptoms and medical resources for creating rehabilitation strategies and reconfigure medical resources according to an individual patient's definite requirements. The State-of-the-art of RFID for application to body-centric systems in healthcare industry is presented [41]. RFID technology, especially passive RFID systems, are used for gathering information of the user's living environment and human behaviour. E-Heath to mobile Health (mHealth) with mobile platforms [42] is presented to perform continuous and remote vital sign monitoring with Internet capabilities. Combining ontology systems and representational state transfer (REST) full service, IoT-based applications and object semantic management platforms are presented to describe a Product Lifecycle Management (PLM).

IoT used in various industries

Oil spill detection with intelligent systems offering high-performance computing, energy efficiency, and consistent operation are proposed as marine applications and environments [43]. The success of Oil spill contingency depends on powerful computing infrastructure and remote sensing networks which can collect real-time data in the ocean with higher accuracy.

Furthermore, currently more and more researchers propose IoT-based applications for smart cities. Smart community [44] is associated with communications and ubiquitous sensing technologies that enable connectivity to the smart homes in local communities, and provide several useful functions for local residents. Two smart community applications – Neighbourhood Watch and Pervasive Healthcare have been presented as describing how to realize secure and robust networking among applications. Authors explore how Internet of Things (IoT) on Enterprise Systems (ESs) support data acquisition, communication, and decision-making activities which definitely require real-time data collection.

This thesis discusses the interaction between humans and things [45]. Because of the previously low recognition rate, new technology based on Internet of Things has been developed for intelligent traffic monitoring systems [46]. This new approach used global unique EPC (Electronic Product Code) to identify vehicles using RFID readers, positioning information from GPS technology and GPRS scheme to transmit data with high-speed wireless IP services.

Internet of Things help to improve logistics monitoring

A modern logistics monitoring platform based on the Internet of Things is presented [47]. In this study, a global unified electronic product code (EPC) and global positioning system GPS are used for building a platform and the function requirements of the system is proposed. The paper [48] presents an Internet of Things for transport logistics, based on a standards-based approach for connecting the information and material flows in logistics processes. A way to improve detecting the presence of the person inside– Device free Passive Localization (DfPL) can be a good alternative option among various techniques in indoor passive localization, e.g. Ultra wide band (UWB), physical contact, differential air pressure, computer vision, and device-free passive location (DfPL). Ultra-wideband technique [49] uses through-the-wall surveillance or through-wall imaging techniques, being used for both static and motion detection inside. This UWB technique is currently well used in various industries, e.g. law enforcement agencies, military and civil services.

Airbus estimates location based on indoor airflow disruption caused by human movement. An air pressure sensor which is placed within HVAC units detects pressure variations to identify an open or closed door correctly with HVAC in operation [50]. Computer vision based systems depend on location information are regarded as Device free passive location systems [51]. EasyLiving project [93] in intelligent environments which is a computer vision based system identifying the possibility of obstructions and trying to solve them to make the technology practical. This project successfully shows the person-tracking system running well, and it can track multiple individuals' movements.

2.3 Building occupancy system by RFID technologies – Internet of Things

Technological advances continue to spur wireless sensor networks and internet which can provide communication between computers in distant locations, even in the situation all communication systems are non-operable. The WSN and internet carry an extensive range of information resources and services on a global level. Moreover, the phenomenal level of growth of wireless technology is able to access the information remotely by Bluetooth, Wi-Fi or IEEE 802.11, Ultra Wide Band, Zigbee, 3

G and Satellites etc. from everywhere around the world with smart devices. This idea is extended to the formation of the inter-connection of uniquely identifiable embedded computing devices within the existing internet infrastructure which is the Internet of Things (IoT) [52] Sensor which is assisted wireless communication in self-configuring wireless networks to create new environments where objects can sense and communicate to other objects and to people. The IoT creates an environment that gathers information from multiple devices including almost anything with a sensor and applications and provides the information with knowledge that enables ease and convenience in everyday living. A wireless sensor network (WSN) of spatially distributed autonomous sensors [53] enables objects and devices from a network to monitor physical or environmental conditions, and exchange data and communicate with each other, also enabling control of sensor activities to sense changes and react autonomously. IoT services will need to operate with standardized technologies or interfaces to query and change its state and retrieve any information associated with it, since the service is connected to the internet [54].

It is brought to realization that new applications enabled by large-scale networks of small devices are able to gather any information from the physical environment, extract data and transmit the data remotely [55]. These small devices have been growing in process power and bandwidth as fast as they have been getting relatively smaller. The smartphone is now used for occupancy systems as it can be used for localization purposes of the individual within the field of the IoT. Their use ranges from simple HVAC Systems in buildings to even advanced detection and reconnaissance systems [56]. Currently Bluetooth is a widely used short-distance wireless communication technology. Bluetooth technology as an indoor positioning technique can be very useful in many scenarios. One type of Bluetooth technology is iBeacon which is a Low Energy proximity beacon and that is the reason why iBeacon can be used for occupancy systems in buildings.

We have to understand clearly the differences of location and proximity. The terms *location* and *proximity* must be clearly defined in relation to building occupancy systems even though the words are similar to each other.

The term location in geography is used to identify a point [57]. A location is a fixed point or area of space, e.g. city, state, province so on. Location technologies such as GPS or cell tower mapping can help to answer the question of "What is someone's location". But location technologies can only be precise up to a street or building address. With the help of location technologies, we can reach buildings, or nearby places.

In contrast to the term *location*, *proximity* can be defined as "nearness in place or time" or "nearness or closeness in a series" [58]. Rather than an exact location, *proximity* is defined in relation to nearness to another point. Proximity technology can be used to provide location information but specifically its technology can provide micro-location as this can provide much more accurate information, especially in buildings. iBeacons as proximity technology can provide both the exact location in a building and/or to a nearby item of interest, regardless of its location. One example for usage of proximity technology is an electronic art gallery guide which identifies what is nearby by knowing proximity information rather than knowing where the individual is and where the art is displayed. This proximity technology is operating based on comparing the two points.

Proximity technologies are technically based on a different set of technologies than location technologies. Proximity is focused on indoor systems, based on shorter-range technologies such as Wi-Fi, WI-Di or BLE (Bluetooth Low Energy) based iBeacon. The table below clearly identifies the differences between *location* and *proximity.*

	Location	Proximity
Technologies	GPS, Wi-Fi and WI-Di	iBeacon, Bluetooth and TDOA
Purpose	Directions	In-building nearby
Accurate	10s or 100s of meters	Centimetres to meters

Table 1. Differences between location and proximity [59]

2.4 RFID Solutions – Internet of Things

Wireless positioning using Bluetooth technology has been considered in light of the various approaches discussed in the previous theoretical research. A possible Bluetooth positioning solution will be discussed. Bluetooth Low Energy based iBeacon is proposed as the most practical system. In this section, some popular methods for indoor wireless positioning systems and possible applications which are already discussed and implemented will be described.

Methods for Indoor wireless positioning system

Most popular methods of Indoor wireless positioning systems include Angle of arrival, Distanced based triangulation and Fingerprint based positioning [60]. Angle of arrival (AOA) is a geographic positioning method or triangulation method. Distanced based triangulation is the distance between mobile device and the receiver being estimated by RSS (Received Signal Strength), TOA (time of arrival), utilises received signal phases and the other techniques. Fingerprint based positioning is a relatively new positioning technology and this technology can show very strong site specificity because of dependency of received signal.

Possible applications for indoor direction finding and proximity

GPS and Wi-Fi technologies can be used for indoor direction finding but are limited as they can only provide location services rather than proximity services. Therefore, there is a need to investigate possible applications or technologies which can provide indoor direction finding and indoor proximity. *One use of technology for indoor direction finding is to find a parking spot in massive parking garages.* However, the limitation of

GPS technology is that this technology can only guide a vehicle to an area, not to the fixed point i.e. the parking space. *Enhanced retail solutions* is used by major retailers to enhance shopping. Previously Near field communication (NFC) which is used to simply transmit information through to a tablet or smart phone has been used but it is not currently used much. Radio frequency identification (RFID) which can be used to transmit information is often used and will have a place but iBeacons Bluetooth low energy looks set to take over because of iBeacons' wealth of extra functionality. iBeacons could possibly offer payment functionality and can be personalised to engage customers for shopping. Instead of paper brochures, iBeacons is *radically changing the way people interact with public spaces, e.g. Museums or cultural spaces*. iBeacons can allow visitors or people to leave comments on particular items, determine next specific items, bookmark any items for browsing later and provide a contextual interactive guide as well as presenting information to visitors or people based on their location.

2.4 Data analysis method

The proposed system is to track indoor positioning of employees using iBeacon and RSSI (Received signal strength indicator) is incorporated to estimate the proximity. The purpose of this project is to get a clear insight into occupants within open office (refer to figure 2) and Training Room spaces (refer to figure 3) and see/monitor their interactions. The modified beacons are used as location marking device and smart phones or tablet devices are given to the employee as scanners. The system scans the area for the Bluetooth device (beacon) and the scanning process results in a RSSI for the discovered beacon device. The signal of the RSSIs inproposed systems is collected to be used as training data for a classifier and the data is normalized for predicting the occupancy proximity. I may adopt a K-Nearest Neighbours classifier to measure the location of the each test point. A test point consists of more than 2 RSSI readings from each device. KNN classifier with N = 3 to obtain proximity data is run by using test point and training data.

Chapter 3 Research methodology

Three (3) main research methods are included in this thesis – Literature review, design science and experimental study. Chapter 2 provides a review of the relevant literature on the topic related to the current state of the art in smart buildings, models, and their particularities. The relevant literature is collected from various research or case studies from IT companies. This chapter provides a review of relevant literature that reports research findings related to the current state of the art in smart building systems (especially in HVAC systems), models, and their particularities.

3.1 Literature review method

A comparative literature review has been adopted in this thesis to review the various perspectives and wide range of literature on the Internet of things. The literature firstly focuses on how the Internet of Things (IoTs) is driving innovation, from automotive industry, energy, healthcare, industrial, retail and smart buildings, etc. Therefore, IoTs can help to reduce energy consumption in HVAC system. The reviewed literature and research was collected from a large number of online libraries or databases of IEEE, ACM and Science Direct etc. and referenced from a global IT company's database who is leading sponsor of the world's largest and most comprehensive IoT event. Because 85% of things are still unconnected [61] (even though IoT has enormous potential for economic value and to aid social change) I first sought a global IT companies' perspective or vision for IoTs. The industry has yet to understand IoT's enormous potential however, global companies are starting to focus on IoTs with "BIG DATA".

3.2 Design science method

Design science paradigm is utilised in the second part of this thesis involving a quantitative approach. The design science method is an information technology methodology and is mainly based on experimental result and outcome. When research needs specific guidelines for evaluation and iteration within research projects, this methodology is often used [62]. This methodology is mostly used for Engineering and computer science disciplines because Design science research mostly focuses on the artefacts solution, not natural solutions. However design science research or methodology always demands new ways or innovative ways to resolve specific problems. I refer to figure 7 for design science methodology processes.

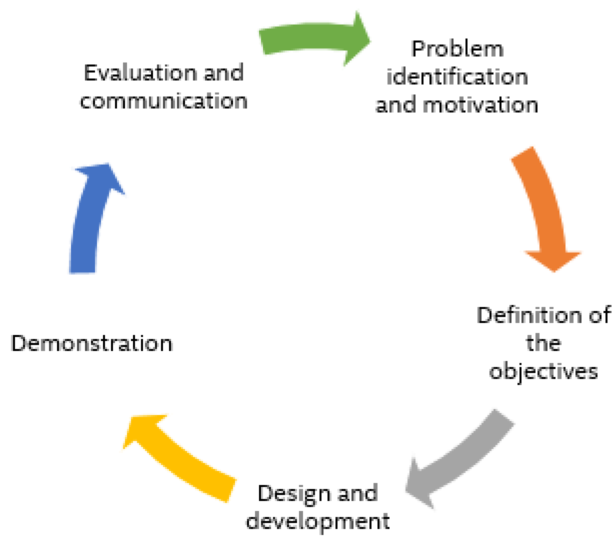

Figure 7. Design science methodology processes [63]

I regard the literature review and consideration of current technology trends as the problem identification and motivation part of this methodology. Definition of thesis objectives is referred from prior research experiment for the solution phase in the design science methodology. Prototyping and modifying the beacons is the design and development phase in science methodology. The experimental process and evaluation part of test is the evaluation and communication processes of this methodology.

iBeacon is modified to meet the requirements of this thesis and this requirement needs field experimentation to retrieve and analyse actual data to confirm reliability of the test. For this thesis, the design science methodology is preferred when compared with other methodologies because it allows the development and application of the designed artefact to resolve any issues that may arise [64].

3.3 Experimental testing

Though experimental research has a range of definitions, it could be objectively defined as the range or collection of experiments where there is manipulated and controlled testing to analyse an underlying process. Therefore this method plays a very important role in this research. This method is commonly used in sciences including chemistry, biology, physics and sociology etc.

Experimental research is adapted often for 1) time relationship in causal relationship, 2) a cause leading to the same effect and 3) great magnitude of the correlation between causes and effects [65].

Four major research approaches were considered

1) *True experiment* – this is ideal for maximizing internal validity and is called a true experiment.
2) *Repeated measures* – all observations are administrated to all subjects which has the advantage of requiring only a small group. Expected disadvantage may distort result.
3) *Quasi-experimental designs* – randomization makes it improbable that one group will be significantly superior in ability to another. This design has been used for the long-term effects of computer experiences by elementary students [66]. Quasi-experimental designs' advantage is convenience and practicality.
4) *Time series designs* – this approach is the repeated measurement of a group, which is the opposite of a true experiment. This design is utilised relatively infrequently in current research literature.

The True Experiment approach is implemented for this thesis and the applied steps are followed [67].

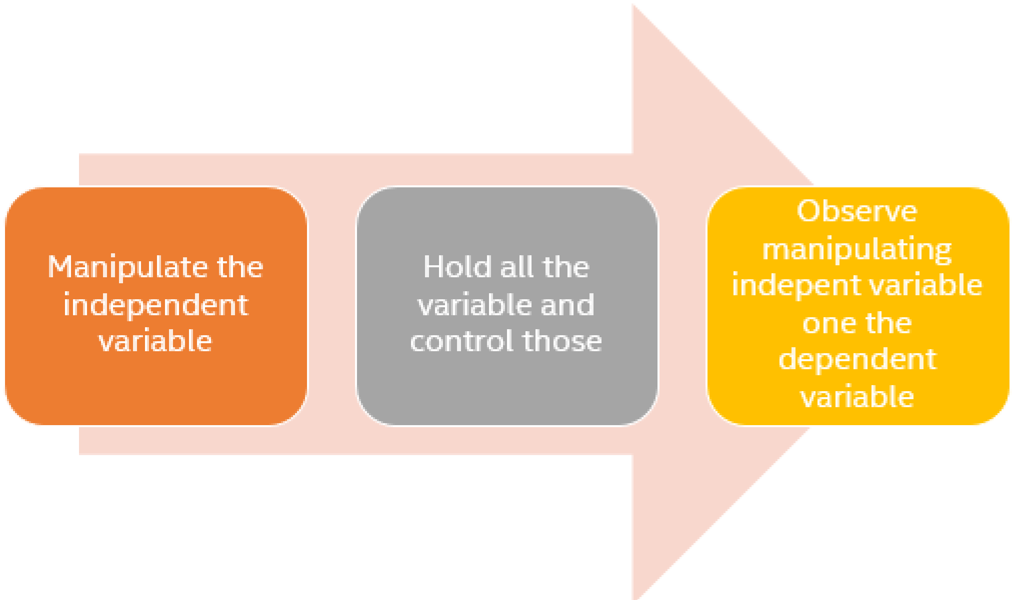

Figure 8. Steps for true experimental

In this thesis, I conduct simulations of Beacon providing applications with proximity information and developed a location-aware application to solve "*occupancy detection problem*". This true experiment is conducted in a real world office environment.

3.4 Methodology justification

In this research, I would like to solve the problem of retrieving the location of users in offices or a building. The proposed technology, iBeacon, may not be able to solve the above mentioned problem, *occupancy detection problem*, due to its original functionality as an indoor proximity system. However it may be possible to adapt iBeacon as a one off solution to the *occupancy detection problem* to enable it to detect the number of occupants in an office, and to gather information of their movements. Though an indoor proximity system cannot provide an accurate position within an office, iBeacon may be able to provide more accurate position information as its transmissions can trigger a device to detect a more precise location by RSSI (Received signal strength indicator). Thus it is possible to identify and track occupants. This means the prototype application will be the artefact to which I implement some modifications. Refer to figure 7. Design science methodology processes, necessary procedures of design science research [68] could be applied for the research and validate that the research method is appropriate for this thesis research. True experimental research approach which is an ideal research method for maximizing validity is invoked in the evaluation period. The evaluation is assessed to analyse the proposed artefact for research objective. True experimental testing approach is suitable for the research, specifically for the evaluation period.

Chapter 4 Prototyping software application development

4.1 Literature review method

The occupant detection problems continue to be researched in the literature and numerous works have been introduced to figure out a cheaper, simpler, more energy efficiency and reliable solution. However, the identified problem still remains unsolved and requires an optimal solution. The main difference among the occupancy detection systems is that most applied technologies offer different approaches to solving the problem.

One proposed system utilises infrared sensors [69] to develop an occupancy detection system which requires both users and the building operator to install and provide extra devices for the normal operation of the system. There are two pre-requirements for this solution. First, users must wear an active badge that broadcasts a unique identifier. Second, a number of infrared sensors are required for the purposes of testing in a commercial building. Collisions occurring during testing meant this system didn't provide accuracy of detection. Due to this serious problem, this solution was never used for the purpose of occupancy detection.

Currently, RFID technologies are utilised very often [70 and 71]. However, similar to the Infrared sensors, the RFID solution also requires the placement of several antennas in the test spaces. Multiple antennas are required due to the limited range of each RFID. The identified range of RFID is only six (6) meters approximately. Occupants must possess passive receivers communicating with tags at all the times inside building. The tags receive a signal and are activated only when they enter the identified range of an antenna.

The measure of time-of-flight of ultrasound pulses [72] was proposed. Occupants continuously wore transmitters and the transmitters were detected when the receivers were within range and any position in the tested area. This approach also has potential problems as the tested position of every antenna must be identified and its location recorded.

GSM technology [73] was proposed as one solution for the occupancy detection problem. GSM devices are already installed in smartphones and antennas are also installed by mobile telecommunication providers. However, the accuracy of this method was very low and varied from 57% to 97% and this variance is the main drawback to the GSM approach.

The most well used approach is Bluetooth as [74] this technology allows short distance communication with relatively low power consumption. This approach is preferred for a project where battery life is very important. Especially when K-Nearest neighbour algorithm (KNN) [75] is used to predict the location of the occupant as I adopt KNN algorithm for this thesis.

4.2 Prototype system application development

For this research, I needed to modify iBeacons as a one off solution to resolve occupancy detection problems because of iBeacons' main limitation i.e. that the iBeacon is transmit-only device. In order to overcome the limitation, I modified and implemented a "protocol" that delivered numerical identifiers to nearby clients.

4.1.1 Equipment selection

Each Bluetooth Low Energy (BLE) device sending advertises packets through the iBeacon protocol consists of three numerical identifiers as follows. First, Universally Unique Identifier (UUID) which is a 128 bit value to identify unique elements. UUID used by a Bluetooth device is used to identify the iBeacons' region. This identifier sits at the top level of the hierarchy of numbers and is created by random number generators.

C743365A-C141-4C43-8A45-E258F7755D5B

- Even though Bluetooth including iBeacon device specifications place no structure for both major and minor value, 16-bit unsigned ***major number*** is typically used for grouping related beacons that have the same proximity UUID;

- A 16-bit unsigned ***minor number*** is used to identify the lowest level of the hierarchy within the set of iBeacon and with the same proximity UUID and major value

Universally unique identifier (UUIDs) are unique and mandatory but the other two values (major number and minor number) are optional. The device advertising packet contents are quite simple and flexible with few variable parameters but have the same length and are composed of a series of fixed fields as in the figure below. iBeacon can run and operate with such a simple protocol as it only needs is to transmit proximity UUID, major number, and minor number.

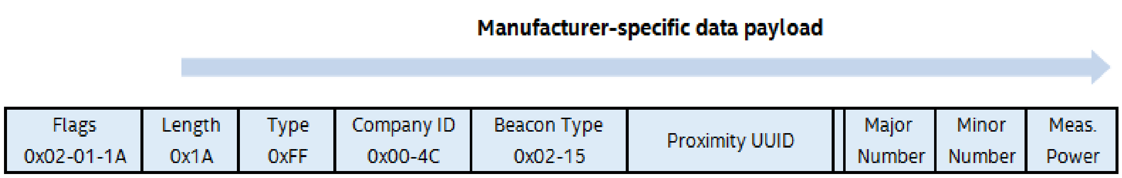

Figure 9. iBeacon packet format

UUID can be referred to as *proximity UUID*, to distinguish one from another a specific test region can be associated with only one specific UUID. For this research, iBeacon

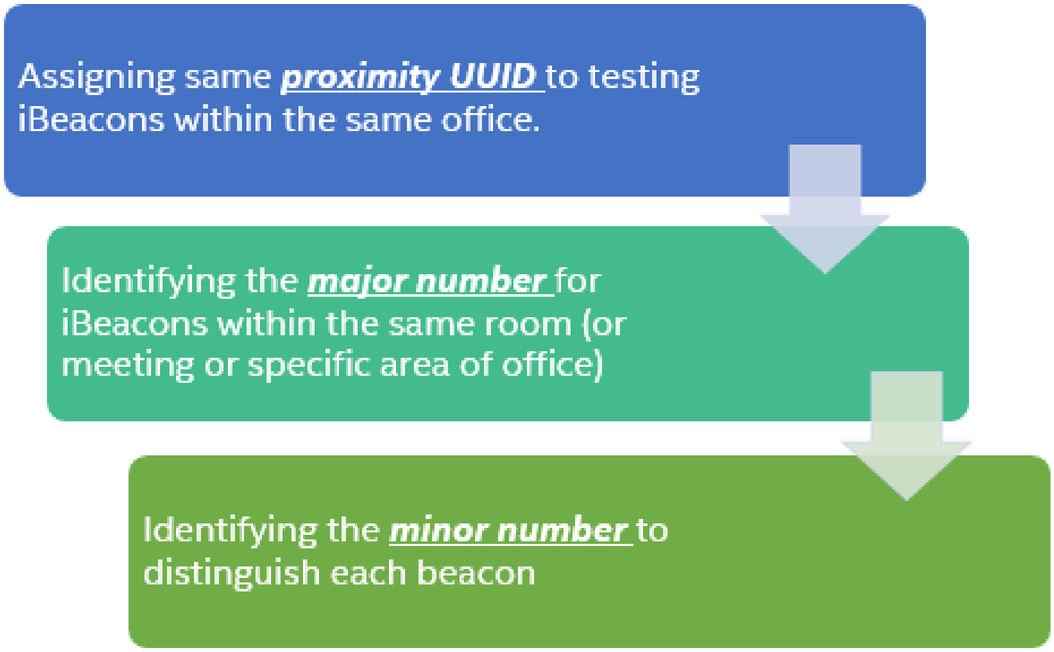

Figure 10. Proximity UUID for test region

functions supported on iOS (only in iOS7 and later versions can support Core Location framework) are provided by framework of ***Core Location***. According to Core Location Framework reference [76], this framework allows users to determine both the current beacons location and geographic regions to gather occupant's location effectively. Core Location provides the straightforward capabilities – e.g. it can monitor regionally and notify when users with receiver devices enter or leave any specific area or zone which is defined by an iBeacon's transmission. The reason for building up an application with associated regions is that iBeacon is a transmit-only device and does not receive or process any information. iBeacons cannot directly interact with other devices; but are triggers for other applications which are activated to respond when a region boundary is crossed.

iBeacon application is used by chain stores, for example, a message would appear on a customer's device i.e. "welcome *to xxx store or display a set of special offers*" when customers or users enter the store and UUID, major number and minor numbers match. For this kind of application, exact location of customers/users is not required. However, when advertising specific products or items, as an example of proximity-triggered action, this application has a much more real time operation and therefore more accurate location and position information is essential. When a device gets close to particular goods, an advertisement, up to date information of goods or notification of a sale etc. can be displayed. Whenever customers/users are close to goods, they can be updated with above mentioned information and any other information directly.

iBeacon enables the communication of a location and position to an application but one of the limitations is that iBeacons cannot perform an action or respond when the device or mobile device is in operation standby mode. Unfortunately, iBeacon technology has not been optimized by Apple Inc. for fine-grained applications because the device or iOS device is basically does not find the monitor when it is in standby mode, and there is no way to keep the monitor active. It requires a high temporal resolution when the device is in standby mode.

However, it could be imagined that one occupant is walking in a building, going to his office at specific floor and passing by several rooms. When the occupant arrives at his office and desk, the lighting system is operating and automatically turned on, with a maximum delay of 2-3 seconds. It could be irritating to occupants that the automation is not activated immediately. Within the standards of the

Figure 11. Sensors for lighting

iBeacon technology, this kind of immediate behaviour is not so easy to achieve. For the matter of accuracy, any system must track the users without discontinuity, but iBeacon can be received by a user's devices only when an application is active. Even though, iBeacon implementation is available on iOS. When an application is in background or standby mode, we need to firstly wake up the application because the users device receives a region for the first time, or possibly not receive signal from region for more than 20 seconds??. When any event is detected, the application is running, during which it is possible to sense the

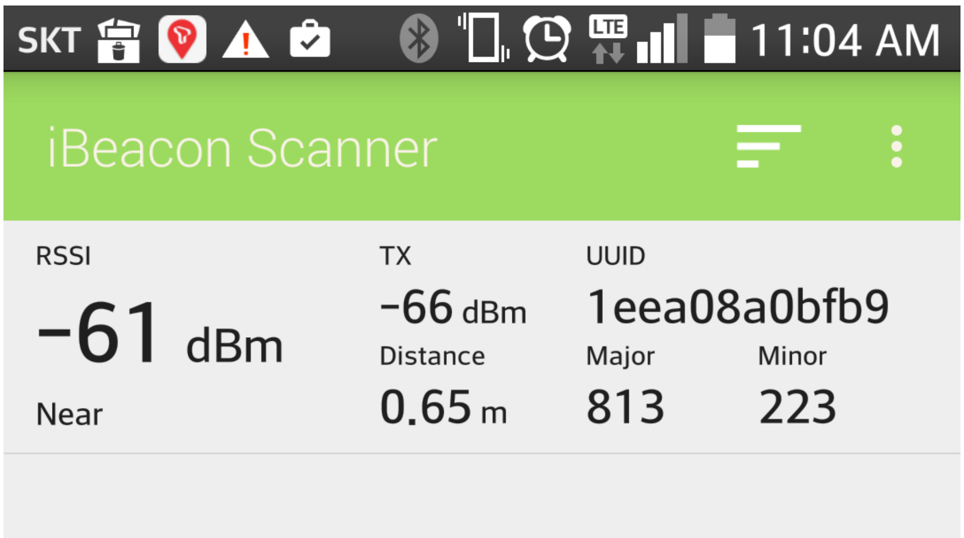

Figure 12. Screen shot of iBeacon scanner to detect redBeacon dongle

beacons and possible to collect information about RSSI, TX, UUID/Major/Minor and distance from the nearby iBeacon or beacons referring to Figure 11. There is one constraint in that it is not possible to make a very accurate occupancy detection system exploiting the information coming from different beacons with different strength levels. For the hardware, iBeacon does not require any specific or specialized hardware but the type of hardware may need to be considered for best performance of beacon.

Dedicated beacon hardware	General-purpose hardware
Estimote	*Macs*
Kontakt	***iOs Devices***
Gelo	*Raspberry Pi*
RedBeacon	*Arduino*
	Nordic Semiconductor

Table 2. Beacon hardware

4.1.2 Software application design and development process

Modification to protocol

In the previous section, the limitations of iBeacons was described. To reiterate, beacons and mobile devices do not exchange transmission but transmit in only one direction i.e. from beacons to mobile devices. Furthermore, Beacons are unable to perform bidirectional communication between devices because of their transmit-only protocol. Beacons are not able to interact with other devices directly but are only able to trigger interaction with other applications. I needed to implement a few modifications to the Beacon protocol as one solution to the occupancy detection problem. The beacon protocol is relatively simple and very easy to be implemented in an application. Even though the protocol is simple it is able to be embedded within an application so that even without internet connectivity Beacons can run continually. The modification is that in the advertising packet of the Beacon I can set up a “region” for monitoring purposes only with three numerical values – UUID, Major numbers and minor numbers – therefore the region can then be defined as two different regions. For example the first region monitors only for UUID and the second region monitors for all values – UUID, Major and minor numbers.

iOS can monitor up to 20 UUIDs and a small modification to the monitoring list can enable more specific monitoring. In particular, whenever the device is in proximity to the UUIDs, an application can monitor for a UUID and the UUID is detected. Then OS can awaken the application which has stopped to start the event. After the application is awakened, it starts to monitor the second region for all values mentioned above and to obtain data from the tested beacons. As explained in the next section, modifying the iBeacon monitoring procedure can make *occupancy detection system* a reality with a high level of accuracy but low level of power consumption. In order to realise this theory, from Table 2 general-purpose hardware, I have developed customized iBeacon as antennas the Arduino UNO R3 with RedBearLab BLE Mini development framework.

Implement system architecture

A validation procedure is required for the proposed system of iBeacon protocol to implement a reliable and low cost *occupancy detection system*. As explained in the previous section, iBeacon is mainly based on the Bluetooth Low Energy (BLE) [77]. Transmitters with Universally Unique Identifier (UUID) and Receivers are the main components of iBeacon's protocol. The role of the receivers is to conduct periodic scanning for any signals for the purpose of detecting particular iBeacon packets. I will explain in the next section the difference between region monitoring and ranging which are the main functionalities for implementation.

Simply stated, the function of monitoring is to notify a listener when a receiver and transmitter with a unique UUID are close each other. On the other hand, the ranging functionality is to provide the distance from transmitter to iBeacon. In this case, the TX power field is used for the transmissions The proposed system is very simple and straightforward. Occupants possess a smartphone or tablet within a test area (i.e. open office and Training room) that is fitted with Bluetooth antennas. Then whenever occupants enter a test area in which iBeacon and any other types of beacon (Redbeacon dongle) are enabled, beacons send a "signal", it is implied that the beacon starts to advertise to the smartphone or tablet holders. Consequently, smart-devices can detect the signal or advertisement from beacons. Finally, smart-devices send back the received information to the application which could be a building management system to control HVAC [78].

The proposed system's architecture is very simple but it must have three main components for normal functionality: the first component is beacons which are specifically named as beacon transmitters and which send uniquely identified beacon packets to smart devices. The second component is client mobile applications to detect beacons firstly and then to send back this information to the application. The final component is an application to receive information from the mobile application and the way to communicate would be either with HTTP request or a Bluetooth connection. The need for an accurate signal analysis is essential and the accurate signal analysis will be examined.

There are many ways to run a beacon with its UUID, major number, and minor number at a fixed interval. For creating a beacon, first, Beacon Hardware needs to be selected. Dedicated beacon hardware is cheaper and much more optimized for the beacon task but for this research RedBeacon is used.

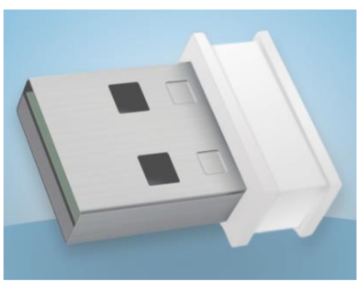

Figure 13. RedBeacon

RedBeacon is a $29 (USD) ea. USB dongle that performs the Transmission functions of an iBeacon. It is fully standalone Bluetooth Smart™ proximity beacon using iBeacon™ and AltBeacon™ technology [79]. It does not require batteries, but is powered from USB port.

Proximity beacon	
Configurable advertisement attributes	UUIDs, Major, Minor, Measured power
Configurable advertisement rate	1Hz to 20Hz
Configurable transmit power	+0dBm to -20dBm

Bluetooth radio	
Version	4.0 (Bluetooth smart)
Frequency	2.402GHz to 2.480GHz
Transmit power	+0dBm to -20dBm
Typical line-of-sight range	5m to 30m
Antenna	Integrated PCB
Hardware	
Form factor	USB Dongle
Electrical interface	USB
Certifications	
Bluetooth	Bluetooth controller subsystem
FCC	FCC part 15 modular qualification

Table 3. Specification of RedBeacon

Beacons are generated by general-purpose hardware and for this research, RedBecaon USB dongle and iOS device iPad3 can act as beacons by the BLE Hardware through the RedBearLab MLE Mini which is development framework. The proposed beacons are adapted to reflect the new the iBeacon protocol. As shown in Figure 15, the hardware of customized beacons is generated using *RadBeacon,* which can add up development platforms to iBeacon.

Figure 14. BLE Mini hardware

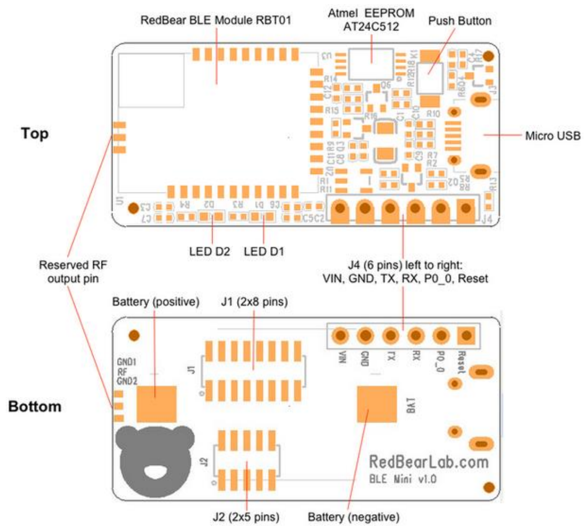

Figure 15. BLE Mini Hardware overview [80]

BLE Mini hardware overviews are

- Dimension is (L) 39mm x (W) 18.5 mm x (H) 2.8 mm
- Onboard programmable components are composed of 512Kb EEFROM, 2 LEDs (Blue & Green) and Push button.

For the experiment, I incorporate Bluetooth 4.0 Low Energy technolgy with BLE mini hardware that can support development platforms of Arduino.

BLE Mini is an ideal prototyping board with Arduino UNO R3 in my experiment. The Arduino UNO R3 is a microcontroller board based on the ATmega 328 that supports the normal Arduino environment. It has 14 digital input and output pins, 6 analog inputs, a 16MHz oscillator, a USB connection, a power jack, an ICSP header, and a reset button - further technical specification are described below.

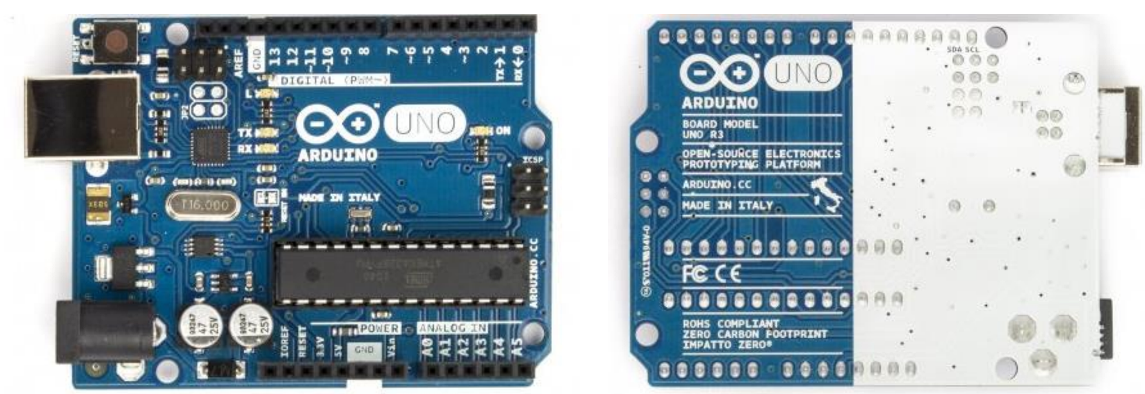

Figure 16. Arduino Uno

Micro-controller	ATmega328
Operating Voltage	5V

Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Table 4. Technical specification for Arduino Uno

Programming functions

There are two ways to transmit location to an application by iBeacons; *Monitoring and ranging*. Both ways are related to a mobile device's position but the information that they convey is different. Monitoring is a one-way function. When the device is within the region it can receive and decode information. Contrary to this, when a device is out of the region then it cannot receive any transmissions. Monitoring operations can be carried out in case of Match UUID only, Match UUID and major number and Match UUID, major number, and minor number. Ranging determines the distance of a device from a particular iBeacon. Any received signal power can be used for distance estimation. For this estimation, the transmission strength and calibration constant are both used. Measuring the range is also used to predict occupants' current location even though this is a relatively high-powered operation.

Application algorithms

In order to solve the *occupancy detection problem*, as was explained and described in previous sections, the iBeacon protocol needs to be modified to enable my experiment. The proposed approach is to modify the beacon's protocol to be able to collect an occupant's location data. After gathering relevant data, I need data processing which refers to the process of converting from collected data to useful data sources. The useful data must be number of visitors, identifier and estimated location of the occupant in the test area. This data processing is referring to data normalization of mapping problems. The location of each occupant gathered from the occupant's mobile device can be mapped to an app. I decided to implement K-Nearest Neighbours (KNN) classification algorithm which is non-parametric method and very good for numerical data. I needed a K-Nearest Neighbours classifier to predict the locations. A test point consists of 2 RSSI readings from each beacon. Using this test point and the training data, KNN classifier with N=3 is run to obtain the predicted location data.

Chapter 5 Experiments and evaluation

In this section, I first describe how to develop applications for the research experiments. Then the experimental setup is discussed. I present the results from the experiments and evaluate its quality. The collected data is analysed and evaluated by the data analysis method.

One open office area and one big training room are used for my experiments and two modified beacons (RedBeacon and iPad beacon) are placed in the two areas. In this way the experiment focused on testing the accuracy of the proposed system with one antenna. For the experiment validation, the research proposed approach is to show that limiting the number of antenna (beacon) can also increase the system accuracy and achieve expected good accuracy results. In order to apply to real work practice, I attempted to enter the two rooms many times to get relevant data for statistical samples as if 50 or 65 employees were currently working in the open office area. One beacon (ReadBeacon) is placed near the A/C unit in the open office and in the Training room. The two beacons are placed in the middle of the test area to maximise the coverage. I have conducted experiments 10 times every day for a week in order to validate whether occupancy can be correctly recognized by the proposed system. I believe the right number of experiments have been undertaken to determine whether the proposed approach is effective in identifying occupancy inside a test area.

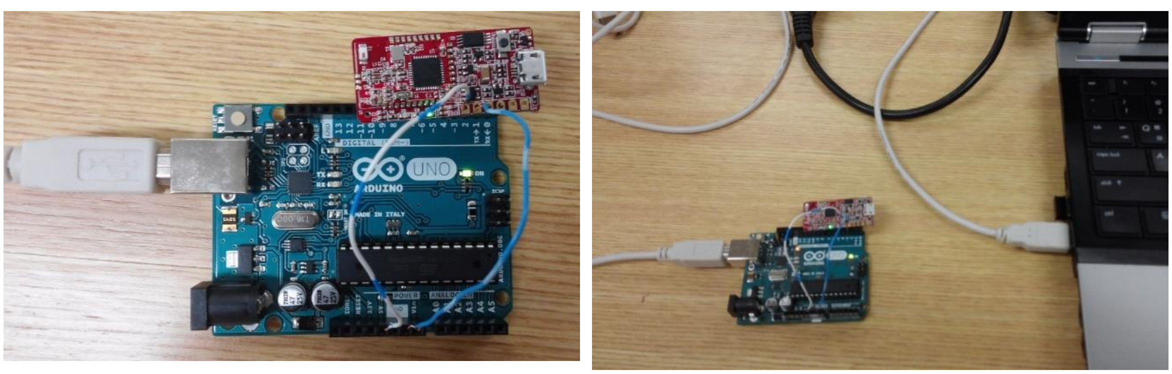

Figure 17. A photo representing the hardware platform used to implement iBeacon

Firstly, the drivers for Arduino need to be installed with Window 7. Arduino UNO (COM5) as serial device of the Arduino board was chosen. The Arduino Uno is a microcontroller board based on the ATmega328. This consists of 8 input/output pins and 6 PWM outputs, 6 analogue inputs, a 16 MHz ceramic resonator, a USB connect etc. [81]. Only 4 output/input are used for modifying iBeacons.

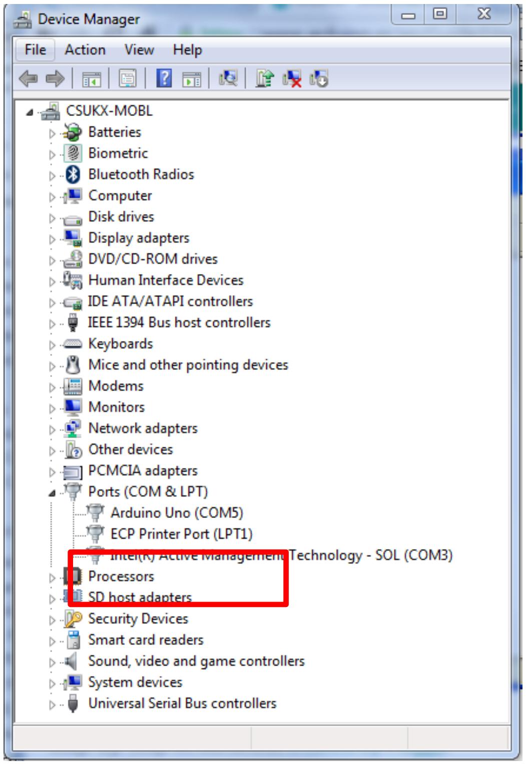

Figure 18. Arduino UNO – COM5

- VIN – this is the input voltage to the Arduino board using power supply to BLE Mini. Arduino supplies power to BLE Mini through this pin.
- GND – This is only Ground pins.
- 0(RX) and 1(TX) – These input and output pins are used to receive (BLE RX connecting to 0) and transmit (BLE Mini TX connecting 1) TTL serial data.

O and 1 pins are connected to the corresponding pins of BLE mini. To communicate with another serial device, AltSoftSerial [82] must be uploaded to the Ardunio UNO platform. This library is specifically need for simultaneous data flows. The library is running up to 57600 baud so use “57600” for client baud. Best reason to use of AltSoftSerial from four serial port options (HardwareSerial, AltSoftSerial,

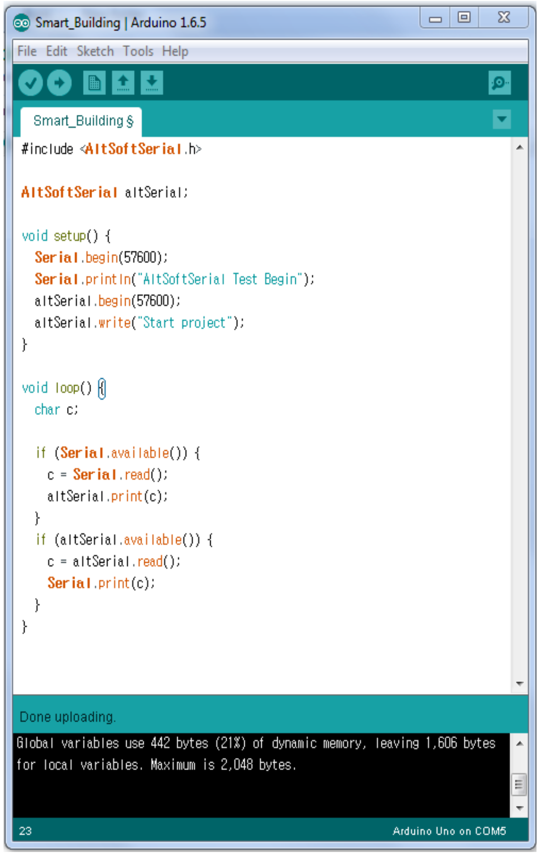

Figure 19. Code of AltSoftSerial

NewSoftSerial and Old Softwareserial) is able to transmit and receive simultaneously. AltSoftSerial always uses below pins for Arduino Uno with BLE Mini.

To incorporate Blue 4.0 Low Energy (BLE) technology in this project with BLE Min, I need to first connect pins from BLE mini "J4" to Arduino Uno development board. To be able to work with iOS or Android, Up-to-date RedBearLab library must be

Board	**Transmit Receive**	**PWM**	**Unusable**
Arduino Uno	9	8	10

Table 5. Arduino UNO connectivity in details.

copied to Arduino's libraries folder. I downloaded BLEFirmataSketch library and compiled and uploaded to projected Arduino board to communicate iOS and Android device. Refer to figure 20, '*Biscuit'* is an open source firmware for the BLE Mini. This firmware provides TX/RX characteristics for BLE central device to send and receive data and the main function for this is to redirect data received from or sent to UART of the TI CC2540 SoC (designed for Bluetooth 4.0 Low Energy applications). Firmware named Biscuit-URT_20130313.bin is designed to communicate with Arduino Uon via UART so I needed to check for the latest release and download the latest “Biscuit UART” version. I used a Microsoft Window PC connecting to a micro USB connector for the upgrade process.

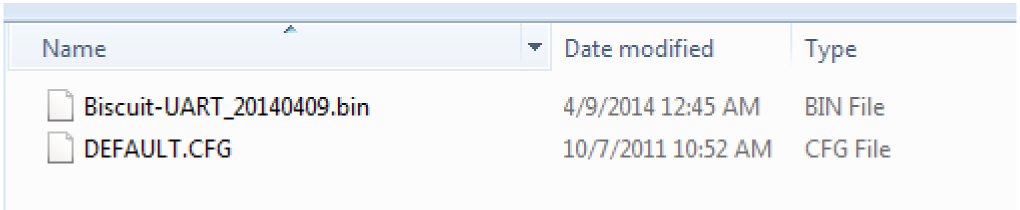

Figure 20. Up to date “Biscuit-UART” copied to BLE mini platform

Even though the Bluetooth connection is affected by the presence of any other signals [83], this is not considered detrimental in this experiment because it does not impact the result of the experiment. To evaluate the fluctuation of the signal received, two variables need to be identified – distance for measurement (meter) and time to detect signal (sec.). Figure 21 below clearly shows the recorded values detected with D = 0.5 meter min and 2 meter max. I cannot find any variability of the estimated distance between the transmitter and receiver. Having a different scan interval is does not impact the results.

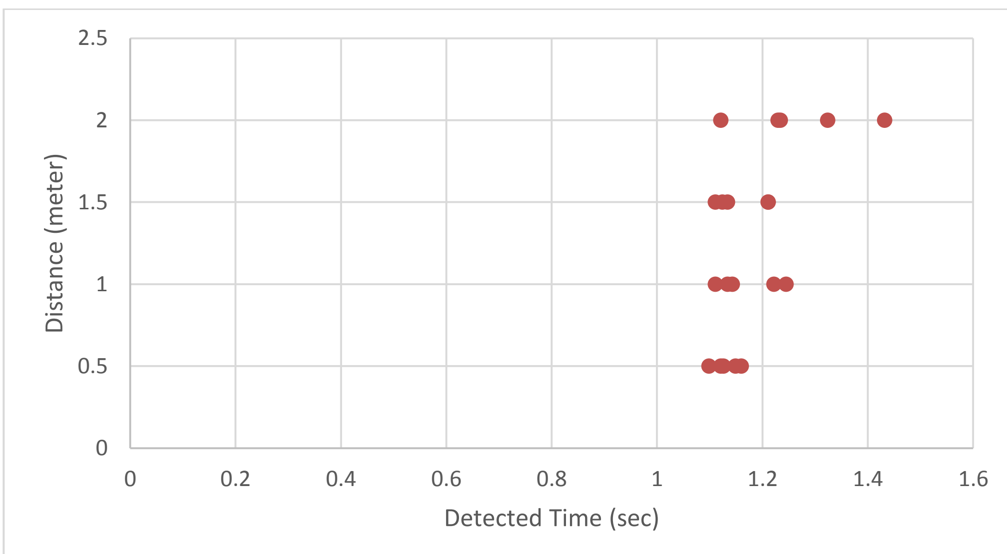

Figure 21. Signal evaluation

Refer to figure 22 for signal evaluation for iOS and Android, whenever there is a difference like above, the detected time variation range is less than 0.5 seconds.

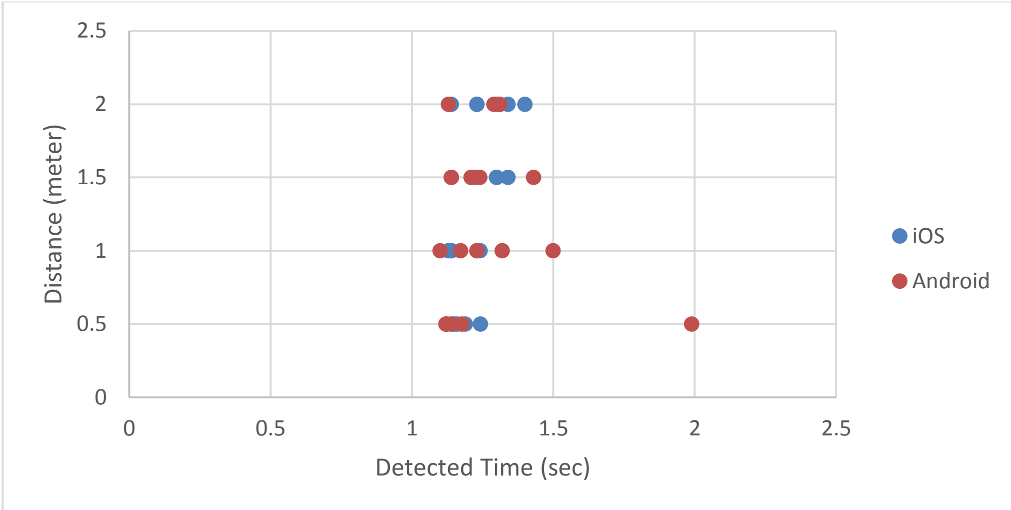

Figure 22. Signal evaluation for iOS and Android

iOS devices and android based devices both collect signals without any differences. This means that iOS operation and Android operation are both accurate in respect of distance measurement results. With this pre-test, I did not need to increase the scan period or interval for obtaining more sample data to give more accurate distance estimations. Corna et al. [84] adapt a co-efficient custom distance estimate algorithm to solve the fluctuation of the signal. However I did not have problems with the fluctuation of the signal in my testing so did not implement the algorithm. During testing, without coefficient the signal is continually stable and responsive to movements with a very small delay.

Determining occupants' position or location is necessary. As I discussed in the previous section, there are methods for estimating an occupants' position. One of the methods I discussed for indoor wireless positioning system is Triangulation. This can provide a three (3)-dimensional tracking solution but does not allow for any small signal fluctuation. Therefore this method is not ideal for this experiment. To increase the classification accuracy, Scene analysis technique [85] and proximity technique are adapted. Scene analysis technique is a pattern recognition method and is very helpful for increasing classification accuracy. Furthermore, Proximity technique uses very strong signals to detect the location of occupants. In this experiment, detected distances and the detection from two (2) different iBeacon transmitters around the open office and inside the Training room are considered as suitable measures.

First, data is collected as an occupant walks around office and sits down on a chair. iBeacons – one for Detection system which is implemented by Arduino UNO with BLE Mini and another for RadBeacon USB - are identifiers and distance between iBeacon and smart device is detected. Second, the collected data associated with the specific area, open office and training room, is sent to the server and stored in the local database for further experiment. Instant and respective distances are continually stored and it is possible to produce experiment results.

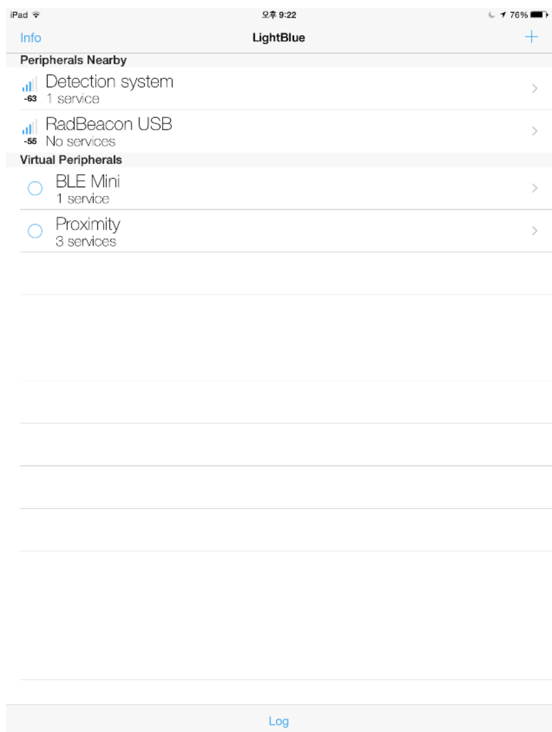

Figure 23. iBeacon scanner

The results being obtained by employing the KNN (k-Nearest Neighbours) algorithm with k equal to 3 are reported. Refer to table 6, the most important variable I have to validate from the experiment is the “accuracy” of detection and the accuracy percent is more than 98%. I chose kfold from ‘kfold’, ‘Holdout’, ‘Leaveout’ and ‘CVPartition’ for computing this value which is number of folds to use in a cross-validated tree and ten(10)-fold cross validation which is default value is used. I collected around 500 training samples and transferred 100 test samples. The clear classifier was identified and can lead to satisfying precision, recall and F-measure and ROC Area. Here recall for kNN is equivalent to the true positive rate. When precision is very high, recall also tends to be high and vice versa.

F-measure is average recall a precision (F-measure = 2*r*p / (r+p)) and ROC area is a receiver operating characteristic metric to evaluate the quality of the output of a classifier. The higher percent of kNN classification results, the better the quality of the output of a classifier.

In fact, if an app is not able to or does not detect when an occupant arrives in the detected area, user experience will be affected negatively. On the other hand, if an app's malfunction causes it to detect an occupant when they are not in the area this does not affect the user experience. This error can be considered as an acceptable error. Very short detection range should be considered and in this experiment, once a smart device is more than 2 meter away, the signal is very week. This kNN algorithm meets the real time performance which is required by this type of experiment.

Correctly classified instances	480 (96.77%)
Incorrectly classified instances	16 (3.22 %)
Total number of instances	496
True positive rate	96.8%
Precision	96.8%
Recall	96.8%
F-Measure	96.8%

Table 6. K-Nearest Neighbors classification results.

Chapter 6 Results discussion and limitations

The clear and straightforward results obtained from this experiment produced very good raw data for further investigation in detail. The statistical classification algorithms I adapted for this experiment are commonly used for experiments of this type (especially for location prediction experiments) and were used only in the rudimentary functions of this experiment. Therefore I still have these algorithms available for further experimentation to obtain optimized results. The best way to adapt the classification algorithms was that Wi-Fi or Bluetooth based implementation can result in most accurate solution in any kind of the proposed application.

On a practical level it is noted that iBeacon related client applications for smart devices or workbench applications on a PC are both easily obtained as a set of development tools and easy to use. For example, one of the development tools, Evothings Studio [86] which is designed for the development of mobile apps using web technologies and especially designed for development of apps for the IoTs are easy to use and provide open source code. Thus, I didn't have any missing values caused by the cyclic behaviour which used to happen when the beacons were operating. Whenever a beacon changed region, both clients – iOS and Android based – detected the signal accurately and it did not affect the performance. [84]'s experiment for occupancy detection by iBeacon NMAR (Not Missing At Random) data but for this experiment this kind of data is not considered.

iBeacon's functionalities are very simple and its protocol is simple so beacons do not require much in the way of configuration. Their identifying numerical tuple the so called UUID, major number, and minor number, only need to be configured, along with a calibration constant to turn signal power received into an accurate proximity measurement.

One of the stages of knowledge discovery in databases (KDD) process is data mining which involves "Classification" of the classes of tasks and which may bring better results for the experiment. The data mining process is very helpful for raw analysis because it transforms information extracted from a data set into an understandable structure for further investigation. It also conducts automatic or semi-automatic analysis of large quantities of data to extract patterns for further analysis. In fact, the data I have collected from this experiment is relatively small but for other experiments, e.g. the prediction of the location of each occupant creating big data, data mining tools will be needed to prevent creating erroneous localizations. For classification, decision trees, random forest, naïve bayes, neural networks, SVM and RVM etc. can be considered but random forests which are an ensemble learning method for classification [87] can get better performance to predict users' localization.

Other variables I would consider for better experiment results are 1) interferences of multiple Bluetooth devices with the application; and 2) the rate of reliability of testing from the different environment conditions. I did not consider those variables in this experiment but to achieve more accurate test results these variables should possibly be considered. An adaptive system [88] which is a set of interdependent entities and forms to integrate all together to respond to environmental changes could offer a possible solution. It has flexibility for environmental changes or changes in the interacting parts. A modified BLE receiver as an antenna can be utilized by feedback loops to sense new conditions in new environments and adapt accordingly as it can automatically re-calibrate the entire network. All improvements for better performance are reviewed but those algorithms and solutions cannot be used for this thesis as they are out of scope. However those variables were raised during feasibility tests for implementing an iBeacon-based occupancy detection system.

In this thesis, I have used mainly BLE mini and modified iBeacon to solve the problems of occupancy detection. In fact, it does not require extra devices for the occupants excepting smart devices, e.g. smart phones which most of people currently use. Furthermore, in the near future more than 50 billion devices are expected to connect to IoT and of course a number of devices will be located in the building to be monitored. As shown in this experiment, even a single or two (2) beacons per area could be sufficient to get satisfactorily accurate results, as opposed to the previous research [70 and 71] which required a relatively higher number of antennas or devices.

Chapter 7 Future work

From the energy consumption point of view, identifying best connectivity from HTTP protocol over Wi-Fi model would be considered. Although it was already discussed that vunerable point for the Wi-Fi communication mode could be the impossibility of having both continuous communication and high energy efficiency, we may need further investigation to find a new solution or technologies which do not rely on the HTTP protocol but increase battery life – even though currently Bluetooth is a relatively power efficient model of communication when continuous communication is required. In this research, BLE communication protocol has been used and clearly identified, this method can achieve higher accuracy of occupancy detection, compared with previously conducted approaches [90 and 91] because the technology and app relating to IOTs is developed.

It was reported that by 2020, more than 50 billion devices will be connected to IoT (Internet of Things) through cloud technology [89]. This technological revolution and high technology model will have a tremendous impact on smart building and smart home industries. The reasons why the impact is expected to be considerable are 1) greatly lowered costs and 2) greatly reduced effort to fit out buildings with sensors, 3) very powerful and advanced cloud-based data analytics. Global corporates, e.g. Intel corporates, are aware of the importance of IoT and will continue to demand data-driven decision support tools for facilitating global adoption of BMSs (building management systems). A recent study by Navigant Research forecasts that revenues for global commercial building automation systems or building management systems is expected to grow to $101 billion in 2021 from $58 billion in 2013, see figure [below]. This forecast clearly comprehends the energy efficiency requirements and future study can focus on this field, especially IOTs for commercial building automation.

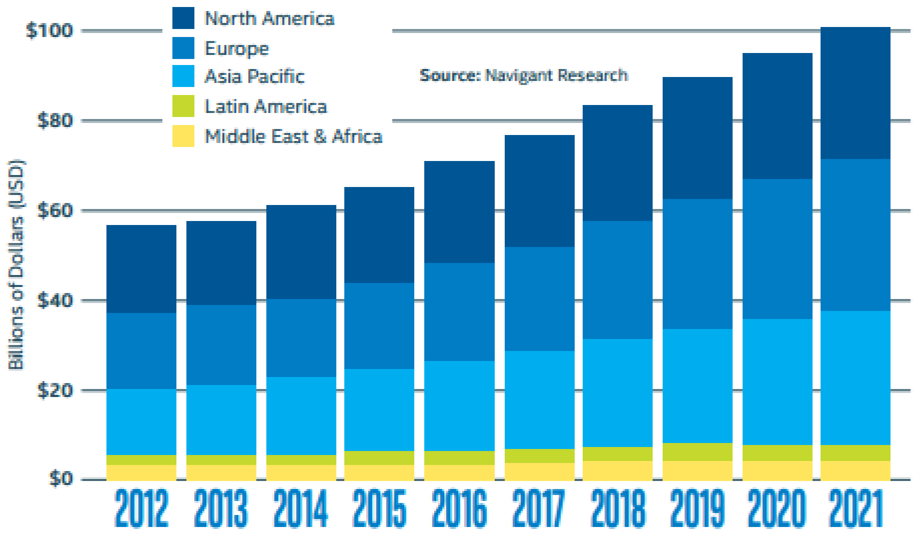

Figure .24 [92] Commercial building automation revenue by region. 2012-2021

Chapter 8 Reference

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Chapter 9 Appendixes – sample data

16:47:21.311 — Bluetooth State: Powered On
16:47:21.319 — Bluetooth State: Powered On
16:47:23.321 — Unable to check for virtual profiles updates from http://punchthrough.com/lightblue/profiles.json
16:47:23.785 — Starting search for nearby peripherals
16:47:23.785 — CentralManager not on, delaying scan
16:47:23.799 — Bluetooth State: Powered On
16:47:23.919 — Starting search for nearby peripherals
16:47:23.989 — Discovered nearby peripheral: RadBeacon USB (RSSI: -68)
16:47:24.043 — Discovered nearby peripheral: detection system (RSSI: -73)
16:47:29.400 — Connecting to nearby peripheral: RadBeacon USB
16:47:29.460 — Connected to nearby peripheral: RadBeacon USB
16:47:29.596 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
16:47:29.654 — Characteristic (2A24) read: <30303031>
16:47:29.715 — Characteristic (2A25) read: <30303030>
16:47:29.774 — Characteristic (2A26) read: <322e30>
16:47:31.267 — Stopping search for nearby peripherals
16:47:37.455 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
16:47:47.445 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
16:47:47.941 — Disconnected from nearby peripheral RadBeacon USB with error: The specified device has disconnected from us.
16:47:54.443 — Starting search for nearby peripherals
16:47:54.460 — Discovered nearby peripheral: RadBeacon USB (RSSI: -71)
16:47:54.984 — Disconnecting from nearby peripheral: RadBeacon USB
16:47:56.700 — Connecting to nearby peripheral: RadBeacon USB
16:47:56.879 — Connected to nearby peripheral: RadBeacon USB
16:47:57.013 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
16:47:57.073 — Characteristic (2A24) read: <30303031>
16:47:57.132 — Characteristic (2A25) read: <30303030>
16:47:57.192 — Characteristic (2A26) read: <322e30>
16:47:58.724 — Stopping search for nearby peripherals
16:48:15.383 — Disconnected from nearby peripheral RadBeacon USB with error: The specified device has disconnected from us.
16:51:58.484 — Starting search for nearby peripherals
16:51:58.635 — Discovered nearby peripheral: RadBeacon USB (RSSI: -66)
16:52:02.753 — Starting search for nearby peripherals
16:52:03.336 — Disconnecting from nearby peripheral: RadBeacon USB
16:52:04.369 — Connecting to nearby peripheral: RadBeacon USB
16:52:04.417 — Connected to nearby peripheral: RadBeacon USB
16:52:04.532 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
16:52:04.593 — Characteristic (2A24) read: <30303031>
16:52:04.652 — Characteristic (2A25) read: <30303030>
16:52:04.712 — Characteristic (2A26) read: <322e30>
16:52:06.156 — Stopping search for nearby peripherals
16:52:22.948 — Disconnected from nearby peripheral RadBeacon USB with error: The specified device has disconnected from us.
16:54:15.749 — Starting search for nearby peripherals
16:54:15.853 — Discovered nearby peripheral: RadBeacon USB (RSSI: -59)
16:54:16.882 — Starting search for nearby peripherals
16:54:17.434 — Disconnecting from nearby peripheral: RadBeacon USB
16:54:18.373 — Connecting to nearby peripheral: detection system
16:54:18.503 — Connected to nearby peripheral: detection system
16:54:20.308 — Stopping search for nearby peripherals
16:56:31.244 — Starting search for nearby peripherals
16:56:32.748 — Starting search for nearby peripherals
16:56:33.323 — Disconnecting from nearby peripheral: detection system

16:56:33.334 — Disconnected from nearby peripheral detection system
16:56:33.464 — Discovered nearby peripheral: detection system (RSSI: 127)
16:56:38.560 — Connecting to nearby peripheral: detection system
16:56:38.676 — Connected to nearby peripheral: detection system
16:56:40.482 — Stopping search for nearby peripherals
16:58:13.915 — Starting search for nearby peripherals
16:58:14.455 — Disconnecting from nearby peripheral: detection system
16:58:14.464 — Disconnected from nearby peripheral detection system
16:58:14.597 — Discovered nearby peripheral: detection system (RSSI: -59)
16:58:16.265 — Connecting to nearby peripheral: RadBeacon USB
16:58:16.324 — Connected to nearby peripheral: RadBeacon USB
16:58:16.462 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
16:58:16.520 — Characteristic (2A24) read: <30303031>
16:58:16.580 — Characteristic (2A25) read: <30303030>
16:58:16.639 — Characteristic (2A26) read: <322e30>
16:58:18.107 — Stopping search for nearby peripherals
16:58:19.267 — Starting search for nearby peripherals
16:58:19.808 — Disconnecting from nearby peripheral: RadBeacon USB
16:58:19.817 — Disconnected from nearby peripheral RadBeacon USB
16:58:22.864 — Stopping search for nearby peripherals
16:58:42.786 — Starting search for nearby peripherals
16:58:42.875 — Discovered nearby peripheral: RadBeacon USB (RSSI: -55)
16:58:43.458 — Starting search for nearby peripherals
16:58:47.412 — Connecting to nearby peripheral: detection system
16:58:47.643 — Connected to nearby peripheral: detection system
16:58:49.361 — Stopping search for nearby peripherals
16:59:11.563 — Starting search for nearby peripherals
16:59:12.102 — Disconnecting from nearby peripheral: detection system
16:59:12.111 — Disconnected from nearby peripheral detection system
16:59:12.200 — Discovered nearby peripheral: detection system (RSSI: -54)
16:59:13.459 — Stopping search for nearby peripherals
16:59:30.719 — Starting search for nearby peripherals
16:59:31.247 — Starting search for nearby peripherals
16:59:43.693 — Connecting to nearby peripheral: detection system
16:59:43.772 — Connected to nearby peripheral: detection system
16:59:45.469 — Stopping search for nearby peripherals
17:00:05.277 — Starting search for nearby peripherals
17:00:05.816 — Disconnecting from nearby peripheral: detection system
17:00:05.824 — Disconnected from nearby peripheral detection system
17:00:05.968 — Discovered nearby peripheral: detection system (RSSI: -55)
17:00:06.157 — Connecting to nearby peripheral: RadBeacon USB
17:00:06.220 — Connected to nearby peripheral: RadBeacon USB
17:00:06.346 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
17:00:06.405 — Characteristic (2A24) read: <30303031>
17:00:06.465 — Characteristic (2A25) read: <30303030>
17:00:06.525 — Characteristic (2A26) read: <322e30>
17:00:08.141 — Stopping search for nearby peripherals
17:00:20.723 — Starting search for nearby peripherals
17:00:21.265 — Disconnecting from nearby peripheral: RadBeacon USB
17:00:21.274 — Disconnected from nearby peripheral RadBeacon USB
17:00:21.364 — Discovered nearby peripheral: RadBeacon USB (RSSI: -47)
17:00:24.320 — Connecting to nearby peripheral: RadBeacon USB
17:00:24.391 — Connected to nearby peripheral: RadBeacon USB
17:00:24.511 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
17:00:24.570 — Characteristic (2A24) read: <30303031>
17:00:24.630 — Characteristic (2A25) read: <30303030>
17:00:24.690 — Characteristic (2A26) read: <322e30>
17:00:26.130 — Stopping search for nearby peripherals
17:00:35.464 — Characteristic (AAA0) read: <52616442 6561636f 6e205553 42000000 00000000 00000000 00000000 00>

17:00:42.708 — Disconnected from nearby peripheral RadBeacon USB with error: The specified device has disconnected from us.
17:00:47.981 — Starting search for nearby peripherals
17:00:48.012 — Discovered nearby peripheral: RadBeacon USB (RSSI: -52)
17:00:48.525 — Disconnecting from nearby peripheral: RadBeacon USB
17:00:49.047 — Connecting to nearby peripheral: detection system
17:00:49.121 — Connected to nearby peripheral: detection system
17:00:50.990 — Stopping search for nearby peripherals
17:01:21.523 — Starting search for nearby peripherals
17:01:22.065 — Disconnecting from nearby peripheral: detection system
17:01:22.074 — Disconnected from nearby peripheral detection system
17:01:22.162 — Discovered nearby peripheral: detection system (RSSI: -55)
17:01:24.252 — Stopping search for nearby peripherals
17:01:27.543 — Starting search for nearby peripherals
17:01:31.411 — Stopping search for nearby peripherals
17:01:42.712 — Bluetooth State: Powered On
17:01:42.719 — Starting search for nearby peripherals
17:01:42.735 — Starting to advertise peripheral Proximity (AAA82E0C-EC49-4621-9D6D-C2A702005805)
17:01:45.396 — Stopping search for nearby peripherals
17:01:55.547 — Starting search for nearby peripherals
17:01:56.571 — Stopping search for nearby peripherals
17:01:57.607 — Starting search for nearby peripherals
17:02:00.946 — Stopping search for nearby peripherals
17:02:33.206 — Starting search for nearby peripherals
17:02:33.636 — Starting search for nearby peripherals
17:02:48.144 — Connecting to nearby peripheral: detection system
17:02:48.380 — Connected to nearby peripheral: detection system
17:02:50.178 — Stopping search for nearby peripherals
17:03:26.385 — Starting search for nearby peripherals
17:03:26.930 — Disconnecting from nearby peripheral: detection system
17:03:26.939 — Disconnected from nearby peripheral detection system
17:03:27.077 — Discovered nearby peripheral: detection system (RSSI: -86)
17:03:30.348 — Connecting to nearby peripheral: detection system
17:03:30.406 — Connected to nearby peripheral: detection system
17:03:32.340 — Stopping search for nearby peripherals
17:03:52.268 — Characteristic (713D0007-503E-4C75-BA94-3148F18D941E) read: <30206442 6d>
17:04:02.256 — Starting search for nearby peripherals
17:04:02.802 — Disconnecting from nearby peripheral: detection system
17:04:02.813 — Disconnected from nearby peripheral detection system
17:04:02.941 — Discovered nearby peripheral: detection system (RSSI: -81)
17:04:04.940 — Connecting to nearby peripheral: RadBeacon USB
17:04:04.993 — Connected to nearby peripheral: RadBeacon USB
17:04:05.427 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
17:04:05.516 — Characteristic (2A24) read: <30303031>
17:04:05.637 — Characteristic (2A25) read: <30303030>
17:04:05.847 — Characteristic (2A26) read: <322e30>
17:04:06.793 — Disconnected from nearby peripheral RadBeacon USB with error: The connection has timed out unexpectedly.
17:04:06.803 — Disconnecting from nearby peripheral: RadBeacon USB
17:04:08.298 — Discovered nearby peripheral: RadBeacon USB (RSSI: -101)
17:04:09.611 — Connecting to nearby peripheral: RadBeacon USB
17:04:09.652 — Connected to nearby peripheral: RadBeacon USB
17:04:09.851 — Disconnected from nearby peripheral RadBeacon USB with error: The connection has failed unexpectedly.
17:04:09.859 — Disconnecting from nearby peripheral: RadBeacon USB
17:04:10.350 — Discovered nearby peripheral: RadBeacon USB (RSSI: -102)
17:04:12.524 — Connecting to nearby peripheral: RadBeacon USB
17:04:12.766 — Connected to nearby peripheral: RadBeacon USB
17:04:13.141 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
17:04:13.200 — Characteristic (2A24) read: <30303031>
17:04:13.260 — Characteristic (2A25) read: <30303030>

17:04:13.321 — Characteristic (2A26) read: <322e30>
17:04:16.116 — Stopping search for nearby peripherals
17:04:27.048 — Disconnected from nearby peripheral RadBeacon USB with error: The connection has timed out unexpectedly.
17:05:00.338 — Starting search for nearby peripherals
17:05:00.362 — Discovered nearby peripheral: RadBeacon USB (RSSI: -79)
17:05:00.885 — Disconnecting from nearby peripheral: RadBeacon USB
17:05:02.071 — Connecting to nearby peripheral: RadBeacon USB
17:05:02.117 — Connected to nearby peripheral: RadBeacon USB
17:05:02.246 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
17:05:02.306 — Characteristic (2A24) read: <30303031>
17:05:02.366 — Characteristic (2A25) read: <30303030>
17:05:02.426 — Characteristic (2A26) read: <322e30>
17:05:04.127 — Stopping search for nearby peripherals
17:05:17.968 — Starting search for nearby peripherals
17:05:18.516 — Disconnecting from nearby peripheral: RadBeacon USB
17:05:18.523 — Disconnected from nearby peripheral RadBeacon USB
17:05:18.668 — Discovered nearby peripheral: RadBeacon USB (RSSI: -80)
17:05:19.567 — Connecting to nearby peripheral: detection system
17:05:19.898 — Connected to nearby peripheral: detection system
17:05:21.704 — Stopping search for nearby peripherals
17:06:52.074 — Starting search for nearby peripherals
17:06:52.617 — Disconnecting from nearby peripheral: detection system
17:06:52.625 — Disconnected from nearby peripheral detection system
17:06:52.765 — Discovered nearby peripheral: detection system (RSSI: -67)
17:06:53.422 — Connecting to nearby peripheral: RadBeacon USB
17:06:53.476 — Connected to nearby peripheral: RadBeacon USB
17:06:53.608 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
17:06:53.667 — Characteristic (2A24) read: <30303031>
17:06:53.727 — Characteristic (2A25) read: <30303030>
17:06:53.787 — Characteristic (2A26) read: <322e30>
17:06:55.187 — Stopping search for nearby peripherals
17:07:11.714 — Disconnected from nearby peripheral RadBeacon USB with error: The specified device has disconnected from us.
17:07:28.102 — Starting search for nearby peripherals
17:07:28.138 — Discovered nearby peripheral: RadBeacon USB (RSSI: -65)
17:07:28.653 — Disconnecting from nearby peripheral: RadBeacon USB
17:07:29.919 — Stopping search for nearby peripherals
17:52:11.868 — Starting search for nearby peripherals
17:52:12.392 — Starting search for nearby peripherals
17:52:15.667 — Connecting to nearby peripheral: detection system
17:52:15.863 — Connected to nearby peripheral: detection system
17:52:17.816 — Stopping search for nearby peripherals
17:52:37.306 — Disconnected from nearby peripheral detection system with error: The connection has timed out unexpectedly.
18:33:09.953 — Starting search for nearby peripherals
18:33:10.155 — Discovered nearby peripheral: detection system (RSSI: -86)
18:33:13.891 — Starting search for nearby peripherals
18:33:14.501 — Disconnecting from nearby peripheral: detection system
18:33:16.565 — Connecting to nearby peripheral: detection system
18:33:16.679 — Connected to nearby peripheral: detection system
18:33:18.674 — Stopping search for nearby peripherals
18:34:05.101 — Starting search for nearby peripherals
18:34:05.667 — Disconnecting from nearby peripheral: detection system
18:34:05.678 — Disconnected from nearby peripheral detection system
18:34:05.811 — Discovered nearby peripheral: detection system (RSSI: 127)
18:34:05.897 — Connecting to nearby peripheral: RadBeacon USB
18:34:06.040 — Connected to nearby peripheral: RadBeacon USB
18:34:06.158 — Characteristic (2A29) read: <52616469 7573204e 6574776f 726b732c 20496e63 2e>
18:34:06.217 — Characteristic (2A24) read: <30303031>
18:34:06.307 — Characteristic (2A25) read: <30303030>

18:34:06.367 — Characteristic (2A26) read: <322e30>
18:34:07.805 — Stopping search for nearby peripherals
18:34:23.781 — Disconnected from nearby peripheral RadBeacon USB with error: The specified device has disconnected from us.
19:13:02.601 — Starting search for nearby peripherals
19:13:02.746 — Discovered nearby peripheral: RadBeacon USB (RSSI: -83)
19:15:12.383 — Stopping search for nearby peripherals
20:11:49.991 — Starting search for nearby peripherals
20:11:50.700 — Starting search for nearby peripherals
20:11:58.266 — Starting search for nearby peripherals
20:11:58.852 — Disconnecting from nearby peripheral: RadBeacon USB
20:11:59.471 — Connecting to nearby peripheral: detection system
20:11:59.883 — Connected to nearby peripheral: detection system
20:12:01.624 — Stopping search for nearby peripherals
20:14:50.976 — Starting search for nearby peripherals
20:15:09.748 — Starting search for nearby peripherals
20:15:10.309 — Disconnecting from nearby peripheral: detection system
20:15:10.316 — Disconnected from nearby peripheral detection system
20:15:10.460 — Discovered nearby peripheral: detection system (RSSI: -64)
20:15:11.597 — Connecting to nearby peripheral: RadBeacon USB
20:15:26.602 — Disconnecting from nearby peripheral: RadBeacon USB
20:15:26.616 — Disconnected from nearby peripheral RadBeacon USB
20:15:26.711 — Discovered nearby peripheral: RadBeacon USB (RSSI: -68)
20:15:29.420 — Connecting to nearby peripheral: RadBeacon USB
20:15:44.424 — Disconnecting from nearby peripheral: RadBeacon USB
20:15:44.440 — Disconnected from nearby peripheral RadBeacon USB
20:15:44.444 — Discovered nearby peripheral: RadBeacon USB (RSSI: -62)
20:16:24.314 — Stopping search for nearby peripherals
21:15:33.829 — Starting search for nearby peripherals
21:15:34.167 — Starting search for nearby peripherals
14:57:32.249 — Starting search for nearby peripherals
14:57:32.261 — Bluetooth State: Unknown
14:57:32.307 — Discovered nearby peripheral: RadBeacon USB (RSSI: -61)
14:57:32.368 — Discovered nearby peripheral: detection system (RSSI: -67)
14:57:56.054 — Connecting to nearby peripheral: detection system
14:57:56.135 — Connected to nearby peripheral: detection system
14:57:57.897 — Stopping search for nearby peripherals
14:58:03.624 — Starting search for nearby peripherals
14:58:04.176 — Disconnecting from nearby peripheral: detection system
14:58:04.186 — Disconnected from nearby peripheral detection system
14:58:04.319 — Discovered nearby peripheral: detection system (RSSI: -60)
14:58:04.467 — Connecting to nearby peripheral: RadBeacon USB
14:58:19.472 — Disconnecting from nearby peripheral: RadBeacon USB
14:58:19.479 — Disconnected from nearby peripheral RadBeacon USB
14:58:19.866 — Discovered nearby peripheral: RadBeacon USB (RSSI: -54)
14:58:21.919 — Stopping search for nearby peripherals
14:58:23.748 — Starting search for nearby peripherals
14:58:50.227 — Connecting to nearby peripheral: detection system
14:58:50.543 — Connected to nearby peripheral: detection system
14:58:52.335 — Stopping search for nearby peripherals
14:59:03.124 — Starting search for nearby peripherals
14:59:03.667 — Disconnecting from nearby peripheral: detection system
14:59:03.676 — Disconnected from nearby peripheral detection system
14:59:03.881 — Connecting to nearby peripheral: RadBeacon USB
14:59:04.030 — Discovered nearby peripheral: detection system (RSSI: -63)
14:59:18.885 — Disconnecting from nearby peripheral: RadBeacon USB
14:59:18.890 — Disconnected from nearby peripheral RadBeacon USB
14:59:19.166 — Discovered nearby peripheral: RadBeacon USB (RSSI: -60)
14:59:21.283 — Stopping search for nearby peripherals
14:59:28.820 — Starting search for nearby peripherals
14:59:30.689 — Stopping search for nearby peripherals

14:59:37.950 — Starting search for nearby peripherals
14:59:55.070 — Stopping search for nearby peripherals
15:26:11.061 — Starting search for nearby peripherals
15:26:11.402 — Starting search for nearby peripherals
15:28:15.768 — Stopping search for nearby peripherals
15:38:40.129 — Starting search for nearby peripherals
15:38:40.738 — Starting search for nearby peripherals
15:40:44.818 — Stopping search for nearby peripherals
16:06:07.062 — Starting search for nearby peripherals
16:06:07.673 — Starting search for nearby peripherals
16:08:28.845 — Stopping search for nearby peripherals
16:26:17.969 — Starting search for nearby peripherals
16:26:18.575 — Starting search for nearby peripherals
16:26:27.373 — Stopping search for nearby peripherals
16:47:22.706 — Starting search for nearby peripherals
16:47:23.088 — Starting search for nearby peripherals
16:49:41.174 — Connecting to nearby peripheral: detection system
16:49:41.325 — Connected to nearby peripheral: detection system
16:49:43.244 — Stopping search for nearby peripherals
16:49:44.911 — Starting search for nearby peripherals
16:49:45.455 — Disconnecting from nearby peripheral: detection system
16:49:45.464 — Disconnected from nearby peripheral detection system
16:49:45.672 — Connecting to nearby peripheral: RadBeacon USB
16:49:51.355 — Discovered nearby peripheral: detection system (RSSI: -88)
16:50:00.676 — Disconnecting from nearby peripheral: RadBeacon USB
16:50:00.681 — Disconnected from nearby peripheral RadBeacon USB
16:50:00.966 — Discovered nearby peripheral: RadBeacon USB (RSSI: -82)
16:50:02.790 — Stopping search for nearby peripherals
16:50:06.336 — Starting search for nearby peripherals
16:50:30.613 — Stopping search for nearby peripherals
16:51:40.869 — Starting search for nearby peripherals
16:51:41.268 — Starting search for nearby peripherals
16:52:18.402 — Stopping search for nearby peripherals
17:01:56.445 — Starting search for nearby peripherals
17:01:56.901 — Starting search for nearby peripherals
17:02:03.136 — Connecting to nearby peripheral: detection system
17:02:03.269 — Connected to nearby peripheral: detection system
17:02:05.177 — Stopping search for nearby peripherals
17:02:06.844 — Starting search for nearby peripherals
17:02:07.387 — Disconnecting from nearby peripheral: detection system
17:02:07.397 — Disconnected from nearby peripheral detection system
17:02:07.606 — Connecting to nearby peripheral: RadBeacon USB
17:02:13.407 — Discovered nearby peripheral: detection system (RSSI: -74)
17:02:22.610 — Disconnecting from nearby peripheral: RadBeacon USB
17:02:22.618 — Disconnected from nearby peripheral RadBeacon USB
17:02:22.924 — Discovered nearby peripheral: RadBeacon USB (RSSI: -91)
17:02:44.711 — Stopping search for nearby peripherals
17:13:08.562 — Starting search for nearby peripherals
17:13:08.913 — Starting search for nearby peripherals
17:13:24.879 — Connecting to nearby peripheral: detection system
17:13:24.934 — Connected to nearby peripheral: detection system
17:13:26.671 — Stopping search for nearby peripherals
17:13:31.257 — Starting search for nearby peripherals
17:13:31.801 — Disconnecting from nearby peripheral: detection system
17:13:31.809 — Disconnected from nearby peripheral detection system
17:13:31.958 — Discovered nearby peripheral: detection system (RSSI: -79)
17:13:33.105 — Connecting to nearby peripheral: RadBeacon USB
17:13:48.110 — Disconnecting from nearby peripheral: RadBeacon USB
17:13:48.119 — Disconnected from nearby peripheral RadBeacon USB
17:13:49.285 — Discovered nearby peripheral: RadBeacon USB (RSSI: -77)
17:14:13.718 — Connecting to nearby peripheral: detection system

17:14:21.347 — Connected to nearby peripheral: detection system
17:14:23.058 — Disconnected from nearby peripheral detection system with error: The connection has timed out unexpectedly.
17:14:23.078 — Disconnecting from nearby peripheral: detection system
17:14:23.503 — Discovered nearby peripheral: detection system (RSSI: -98)
17:14:37.075 — Stopping search for nearby peripherals
17:14:38.694 — Starting search for nearby peripherals
17:14:39.098 — Starting search for nearby peripherals
17:14:53.216 — Stopping search for nearby peripherals
17:22:47.942 — Starting search for nearby peripherals
17:22:48.483 — Starting search for nearby peripherals
17:23:05.597 — Connecting to nearby peripheral: detection system
17:23:05.742 — Connected to nearby peripheral: detection system
17:23:07.490 — Stopping search for nearby peripherals
17:23:13.374 — Starting search for nearby peripherals
17:23:13.917 — Disconnecting from nearby peripheral: detection system
17:23:13.925 — Disconnected from nearby peripheral detection system
17:23:14.159 — Discovered nearby peripheral: detection system (RSSI: -74)
17:23:27.965 — Connecting to nearby peripheral: RadBeacon USB
17:23:42.969 — Disconnecting from nearby peripheral: RadBeacon USB
17:23:42.983 — Disconnected from nearby peripheral RadBeacon USB
17:23:43.438 — Discovered nearby peripheral: RadBeacon USB (RSSI: -77)
17:23:45.176 — Stopping search for nearby peripherals
17:23:46.543 — Starting search for nearby peripherals
17:24:19.891 — Stopping search for nearby peripherals
17:36:20.720 — Starting search for nearby peripherals
17:36:21.309 — Starting search for nearby peripherals