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Development of Multi-Level Indoor Navigation Ontology for Location-Based Services

By

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I, Sanya Khruahong declare that this thesis, is submitted in fulfilment of the requirements for the award of the degree of Doctor of Philosophy, in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

About 90 percent of human activities are in indoor environments. A need for indoor navigation requires Location-Based Services (LBS). The LBS should be able to help people find the best route inside a building under all circumstances and with high reliability, supporting users to navigate to all indoor spaces on every level of a building.

The current research has been focusing on technologies and applications for LBS. There is little work on a standard for LBS. This research contributes to a new LBS standard using ontology theory. Two ontologies are developed in this thesis. Firstly, a Multi-level Indoor Navigation Ontology is developed. This ontology builds the standard for LBS in multi-level indoor environments and considers the building status of emergency and normal states for user navigation. This ontology is designed to present environmental attributes including location nodes, connection points, and building status in a multi-level building. Indoor location nodes with location information allow for navigation within a building, with connection points which can separate the map zones and the building floors. Secondly, an ontology for finding lost property in a multi-level indoor space is developed as a sub-level standard in an LBS application. These two ontologies are validated using experiments using an iBeacon network in a high-rise building.

Keywords: Indoor Navigation, Indoor Space, Indoor Ontology, Location-based Services, Smartphone

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Chapter 1
Introduction

1.1 Thesis

Human activities occur in both outdoor and indoor environments. They use many technologies for navigation to a destination, which have been an essential aspect of human activities. The popularity of navigation technology is the Global Positioning System (GPS). However, GPS is suitable for outdoor travel; it is complicated to utilise inside a building. Effective indoor navigation requires Location-Based Services (LBS). LBS should be able to support people by getting the best route inside a building under all circumstances and with high reliability, assisting users in navigating to all indoor spaces on every level of the building. An indoor navigation system should operate both under normal circumstances and during emergencies; such as fires, during building power shut down, and during alarm. The current research on indoor navigation has been focusing on technologies and applications for LBS. There has been little work on a LBS standard.

This thesis contributes to a new LBS standard using ontology theory, developing two ontologies. Firstly, a Multi-level Indoor Navigation Ontology is developed. This ontology builds the standard for LBS in multi-level indoor environments and considers the building status of emergency and normal states for user navigation. It can support the user in all situations. Environmental attributes of ontology are designed to present information including the location nodes, connection points, and building status in a multi-level building. The indoor location nodes with location information allow for navigation within the building, with connection points which can separate the map zones and the building floors. They can lead to links to all areas in the building. Secondly, an ontology for finding lost property in a multi-level indoor space is developed as a sub-level standard in the LBS application. In this thesis, the approach is to provide a new standard for LBS including the Location-Based Service, ontology, and indoor navigation.

1.1.1 Location-based Services

Location-Based Service (LBS) is a critical component of the mobile infrastructure, which can supply users with crucial information depending on the user's current position (Orehovacki, Stapic & Bubas 2009). LBS is a general class of computer program-level service which includes specific controls for location and time data, as control features. There is considerable navigation research, developed with LBS techniques, which can support localisation.

Espeter and Raubal (2009) describe their prototype used for simulating a location-based decision process aimed at searching for an optimal restaurant for a user group in an urban setting. However, their paper focuses on a search engine for restaurants only. A LBS prototype of restaurants was applied with approaches of multi-criteria for decision-making, including time, geography and defining of measurement of distance. LBS is developed to suggest places recommended by a user's social network (Weiss et al. 2015), where the application may be capable of determining where the people would like to go with similar tastes, and show a rank recommendation. Moreover, Mobile Positioning Center (MPC) presented by caches of location data of the mobile device and returns the location information to the domain name service (DNS) server, e.g. latitude and longitude (Haran, Saxena & Irizarry 2012). This research can be adapted to use a places suggestion system, suitable for outdoor navigation. A Chinese standard for indoor location by (Kang & Li 2017), is called IndoorLocationGML, but it could not provide relative indoor reference systems in explicit ways.

1.1.2 Ontology

Ontology is a set of names and description of the types, properties, and interrelationships of the entities in a particular environment. Ontology has the structure of a dynamic database, which is efficient for LBS searching development (Maedche 2012). The ontology can be developed using the Web Ontology Language (OWL) (Bechhofer 2009). Ontology techniques have led to an ontology framework for indoor navigation systems such as IndoorGML and BIGML (Kessel, Ruppel & Gschwandtner 2010; Kim, Yoo & Li 2014). IndoorGML is the basic concept of the cellular space model, which focusses on the representation of indoor spaces. IndoorGML (Kang & Li 2017) was published by OGC (Open Geospatial Consortium) as a standard data model and XML-based exchange format.

Ontologies have techniques in common with a Semantic Database. There are three fundamental requirements for a fully functioning semantic database: dictionary encoding, RDFS inference, and query processing. Ontologies modeling in computer systems has three models (Lim 2011): top-level ontologies, lexical ontologies, and domain ontologies. Lim's review compared the methods for defining the domain ontology, for finding the reasoning for making a decision which which is different to specific knowledge.

1.1.3 Indoor Navigation

Wang et al. designed an ontology for representing a semantic location in indoor navigation models (Wang et al. 2013). This ontology shows the semantic information and multilayer semantic location, which consists of two types of information: static information such as the structure of the room, and dynamic information such as the sensing areas. However, this ontology is limited to presenting a map of only one floor, not linked to the other floors in a multi-floor building. A hybrid modeling technique is proposed in OntoNav (Tsetsos et al. 2006) by modeling geometric and semantic information for user navigation. The ontology OntoNav addresses the linking of other floors in the building; users need to select the path rule for traveling, and the restriction of the route which the system maintenance is difficult.. A Colour Petri Net model (CPN) using a Resource Description Framework (RDF) for ontology has been developed for an indoor location-based system (Yim, Joo & Lee 2012). This model is able to identify the properties of core classes (such as subject, predicate, and object onto places) and map these properties onto CPN places. This approach may need to be developed with OWL ontology. Scholz and Schabus adopted an ontology to support autonomous indoor navigation in the production environment (Scholz & Schabus 2014). Their research used RFID and ultrasound technology to support autonomous navigation in the indoor space and developed a tracking system called LotTrack. However, the installation of RFID in buildings will require a large investment. Another approach for an indoor location used a Genetic Algorithm (GA) and a neural network (Chen et al. 2015) to collect positional data using RFID tags, RSS information, and four reader devices. This research was limited in scope, covering only one level. Moreover, the researcher presents a new class of the Internet-based indoor navigation (IIN) services (Zeinalipour-Yazti et al. 2017) which provides support to the indoor navigation but this method needs an indoor model of database for floor map and other signals such as WiFi, light and magnetic signals.

The major contribution to this research is the development of two ontologies for a Multi-level Indoor Navigation Ontology for Location-based Services. The design of the Ontology model uses a digital map of each floor of the building linked together with multi-level node techniques. The ontology is intended to describe the nodes for indoor navigation under both normal and emergency situations. The model provides indoor localisation information, which is compatible with Bluetooth devices to determine the user's current position. This ontology model contributes to a new standard for indoor space information for LBS indoor navigation. It can lead to an exchange of position data between all nodes and can be applied to the model for a semantic property of indoor navigation; moreover, the multi-layered space can link a unit of a map node to the semantic description. The multi-level indoor navigation algorithm is developed to be the prototype of an application for validation for use with smartphones.

1.2 Background

New technologies are combining physical, digital and human systems into high assurance modern smart city systems (Wang 2015). The smartphone has a key role in the development of smart city technology for the Internet of Things (IoT). People routinely use Global Positioning System (GPS) receivers on their smartphones for navigation while traveling. However, traveling is not restricted only to the outdoors; there is also a necessity for indoor navigation for which GPS is often inadequate or useless.

Indeed, 90% of human activities occur in an indoor environment (Dehghanzadeh, Ansarian & Aslani 2013). Multiple technologies including Wi-Fi, Bluetooth Low Energy

(BLE), and Radio-frequency Identification (RFID) are currently used for indoor navigation. Support for these technologies requires the correct information presented by a digital map to help users find their position with the required accuracy. Indoor navigation is one of the functions for Location-Based Services (LBS), with high reliability as one of its quality requirements. As well as operating under normal circumstances, the LBS should still act in emergencies, such as building power shut down, fires. The high assurance of LBS should be able to assist users to find the best exit route to the outside of any level in an office building or shopping mall, under all situations, with high reliability. Emergency Rescue Localization (ERL) systems use Wireless LAN (WLAN) and cameras to get the location data inside a building (Bejuri et al. 2015). However, these systems need building power, which may not be available during emergencies.

Therefore, research in indoor wayfinding needs to focus more on complex situations in complex environments. Multi indoor information is thus critical for the development of indoor navigation applications to enable the user to link their current location to other levels of the building and navigate between them or apply them for other uses such as finding items of lost property in the building.

This research develops indoor navigation theories which consist of a travel ontology design including accurate determination of indoor locations using BLE sensors. The ontology patterns will be created for improving knowledge of the constraints to traveling. BLE Devices will be used for indoor positioning because of their ready availability and low cost compared to other techniques. The following research questions have been established:

1). What are the ontology design classes for indoor navigation?

2). What development of a theory for indoor navigation using ontology and devices is necessary?

1.3 Stakeholders, Aims, Objectives and Significances

1.3.1 Stakeholders

This thesis is intended for stakeholders including researchers, developers and LBS owners in the LBS industry who want to develop an indoor navigation standard and implement indoor navigation systems for Location-based Services. Their development needs in seeking indoor navigation ontologies can be met by adapting the techniques developed in this thesis for solving problems of indoor navigation, especially for navigation in corridors and locating objects in the building. The approach used will be applicable for searching applications requiring indoor navigation using a smartphone, with which developers will understand the indoor navigation approach of this research and can apply it to their own needs.

1.3.2 Aims

The long-term aims are to design an indoor navigation model using the ontology design and to apply this to indoor devices for a Location-based Service (LBS). The aims of this thesis are as follows:

Aim 1: to develop indoor navigation ontologies for the indoor navigation system.

Aim 2: to build a validation theory of indoor navigation for location-based service.

1.3.3 Objectives

The theory of indoor navigation will assist researchers or developers to use, in a real multi-level environment, a standard description of indoor space structure and analyze an indoor route using their smartphone. The study has the following objectives:

Firstly, this research will develop the indoor navigation ontology to classify the indoor space into standard component such as nodes, zones, array route, links and building states.

Secondly, the design will be validated to the theory of an indoor navigation system which a software developer can apply to developing an indoor navigation system on their LBS.

Figure 1.1 illustrates the developing view of the indoor navigation environment.

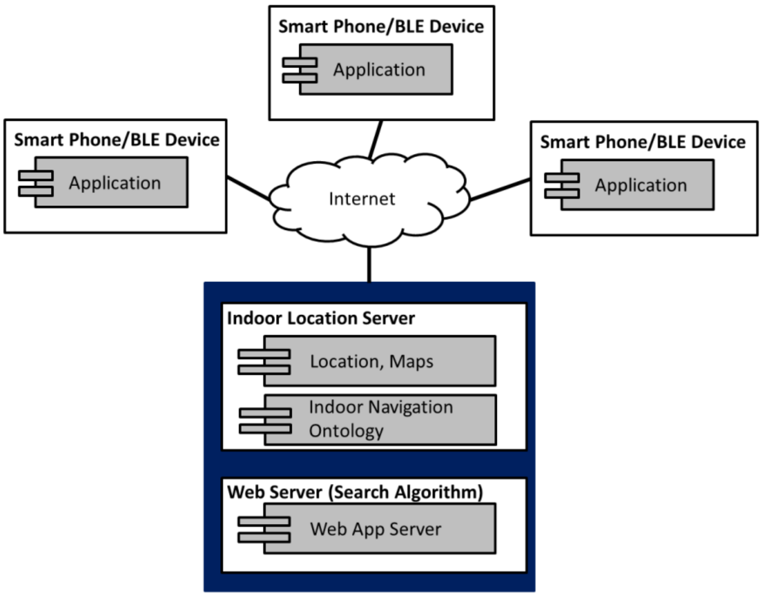


Figure 1.1. Deployment view of an indoor navigation for LBS

Figure 1.2 shows the architecture of multi-level indoor navigation with a digital map. This figure indicates the concept for applying the ontology for indoor navigation using BLE devices for an indoor navigation application on a mobile smartphone.

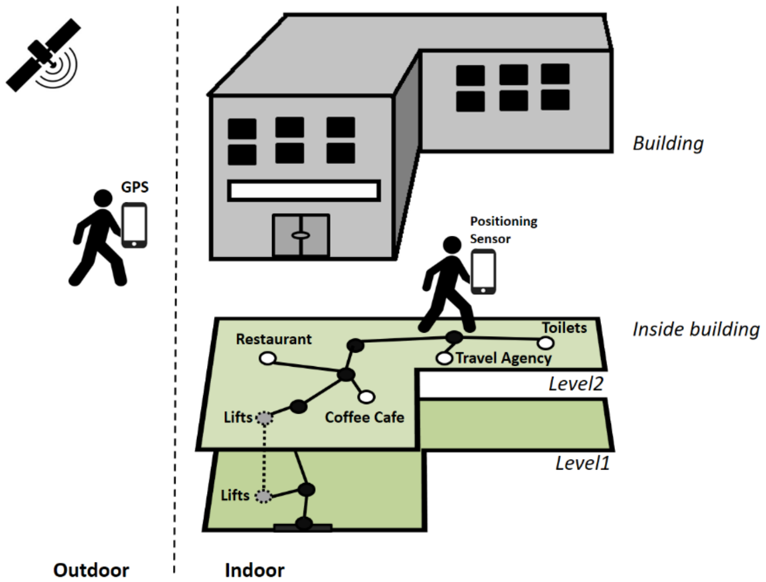


Figure 1.2. Multi-level indoor structure for user navigation

Figure 1.3 illustrates an example of a plan of the fifth level of a building which a human can understand, but only after the building owner has invested in many guideposts for the customers. This research will use the Bluetooth system in a smartphone to look for the indoor positioning and to build a digital map for the prototype. This digital map will be developed with ontology technology for the indoor navigation system.

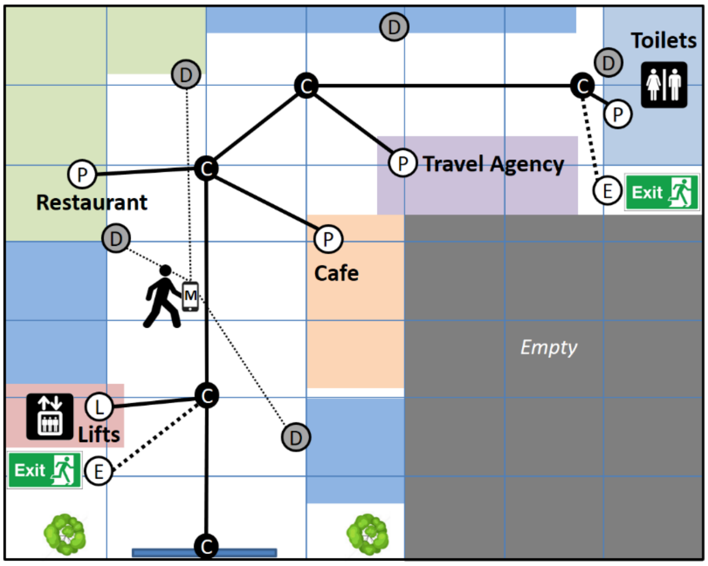


Figure 1.3. The floor of a building

1.3.4 Significance

This research emphasizes the development of indoor navigation standards for LBS. The importance of the thesis is proposing the new standard to classify the indoor environment into ontology class and attribute. This approach can assist LBS in applying to an ontology in a different situation. The location of the user, location and object in building which they are designed as nodes, class ontology and a path of the user are designed as route array and link class in ontology.

When applying ontologies, the location data will be combined with grid coordinates for the particular location on the digital map, where the grid coordinates inside the building are similar to the latitude-longitude pairs of GPS. This location information, inside a building, will be registered in the ontology for indoor navigation and the location-based service. If the smartphone can be synchronized with the BLE devices and the digital map is accessible via the internet, the grid coordinates of the user can be established, for example, the user's position relative to that of a café. This ontology will be used initially to demonstrate the concepts by validation of the indoor navigation mobile application.

This research develops an indoor navigation theory applying to all nodes of the ontology using Bluetooth devices for the location-based service. This approach is beneficial for a developer working on an indoor navigation application. The theory is validated by using a number of test cases in a real indoor environment in a multi-level building.

1.4 Research Methods

The study objective is the development of theories of indoor navigation for location-based service. The research goals include indoor navigation ontology design and ontology validation in a multi-level building.

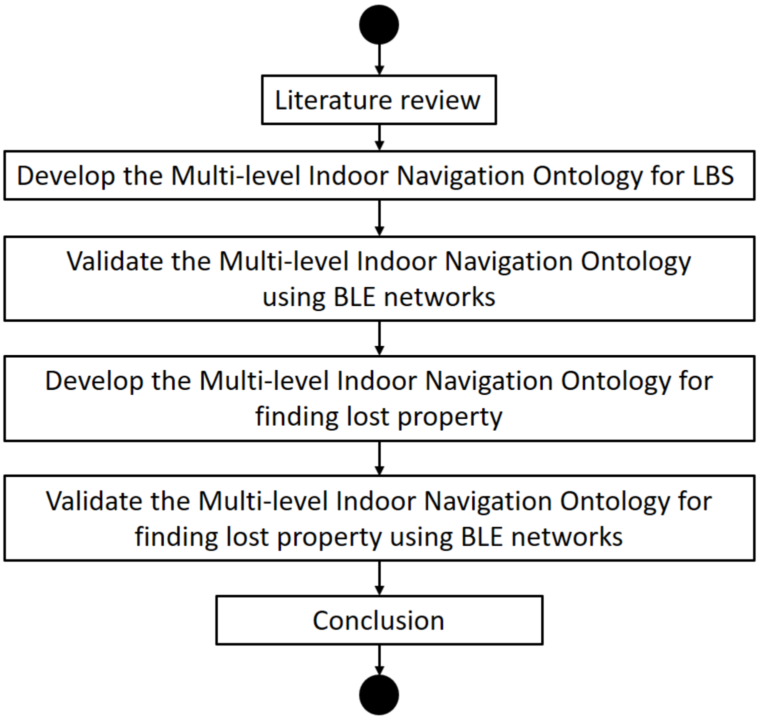


Figure 1.4. The research methodology

This research methodology is as in Figure 1.4.

A. Literature Review

A literature review on indoor navigation, ontology design, and location-based services is conducted. The research needs to provide novel information in the area of ontology design and search engines. The thesis offers a formal definition of ontology, followed by an explanation of ontology in appropriate terms and demonstrated by example, in order to clarify why the ontology is crucial for location searching on a mobile device. The literature on indoor navigation using Bluetooth devices for Location Based Services is reviewed.

B. Develop the Multi-level Indoor Navigation Ontology for LBS

The indoor navigation algorithm for indoor location searching will be built as a theory for location-based services for establishing an optimum route inside a building. The algorithm will be designed for use on a mobile device utilizing an indoor navigation ontology, digital map and battery powered Bluetooth technology. The theory is applicable for indoor navigation in both normal situations and emergency situations and can connect to a different floor in the building, all of which are tested by means of experimental validation.

C. Validate the Multi-level Indoor Navigation Ontology for LBS using BLE networks

The validation of the multi-level indoor navigation ontology was completed using BLE networks and smartphones. It uses the ontology and a digital map of the inside of the test building. Signal information from the long-life battery powered BLE devices is collected for validation. Test cases of the routes are designed for the validation procedure. After evaluation of the efficiency of the theory, a way forward for future work will be proposed for developers.

D. Develop the Multi-level Indoor Navigation Ontology for Finding Lost Property

The indoor navigation ontology for recovering lost property such as a wallet, laptop, is developed to find the best route to the location of these lost items. The theory focuses on the indoor navigation ontology for detecting lost property in the building. It will add some approaches from the Multi-level Indoor Navigation Ontology for LBS. This theory will use Bluetooth devices stuck to each object, which is always moving. Bluetooth devices will be applied to coordinating in two functions both sticking on the wall and holding on objects.

E. Validate the Multi-level Indoor Navigation Ontology for finding lost property using BLE networks

The Multi-level Indoor Navigation Ontology for finding lost property will be validated by testing the ontology class, attribute and route finding. The test cases are designed and tested using several routes, using the indoor maps of the building, and signal information from the Bluetooth devices. The validation results will be used to improve the development of LBS approaches for mobile applications.

F. Conclusion and Discussion

All results from the experiments will be analysed for the validation of theory, and to indicate possible future work in this field.

1.5 Contributions of this thesis

The main contribution of the thesis is the development of theories for indoor navigation applications using an indoor navigation ontology. The main contributions of this thesis are summarised as follows:

- The development of a multi-level indoor navigation ontology for LBS
- The development of the indoor navigation ontology for finding lost property
- The development of a node structure for an indoor environment in a multi-level building
- The development showing how to link the different levels of building and space for connected nodes for LBS
- The development of route array algorithm in a multi-level building navigation
- The development of multi-level route finding algorithm for LBS for emergency and normal situations inside a building
- The demonstration of indoor navigation for LBS using iBeacon Bluetooth devices

1.6 Structure of the Thesis

The remainder of this thesis is organized as follows:

Chapter 2 reviews the existing work related to this research, including research on theories of navigation, location-based services, ontology, and indoor navigation ontologies. Related work on data models and formal spatial models are introduced, including work on navigation graph generation.

Chapter 3 presents the multi-level indoor navigation ontology. This chapter will present the indoor navigation task ontology with regular and emergency situations.

Chapter 4 presents the multi-level indoor navigation ontology for finding lost property. Extensions to the theories and their computational algorithms are introduced. A new indoor navigation approach is proposed for finding lost property.

Chapter 5 analyses the validation results and includes discussion of test cases which were implemented to demonstrate and evaluate the approach proposed in Chapters 3-4. The case studies are designed and implemented for ontology evaluation.

Chapter 6 concludes this thesis. It provides an overall summary of the significant results of this thesis. It also discusses future research areas.

Finally, the appendices provide the definitions of concepts involved in the ontologies presented in Chapter 3-4, and detailed algorithms used in those computational algorithms introduced in Chapter 3-4.

Chapter 2
Literature Review

This chapter reviews research related to this thesis and leading to the development of an indoor navigation model, including Internet of Things (IoT), Location-Based Services (LBS), Indoor Location-based Service, Ontology and Ontology with Indoor Navigation.

2.1 Location-Based Services (LBS)

A Location-Based Service (LBS) is a critical component of mobile infrastructure, which can supply users with crucial information relevant to the user's current position (Orehovacki, Stapic & Bubas 2009). LBS is a general class of computer program-level service which includes specific controls for location and time data as control features. There is a lot of navigation research developed with LBS techniques, which can support users' travels. In LBS, location measurements from sensors are meaningful only when they relate to their surrounding environment. Ontology is a tool for representing the knowledge of a location's environment.

Some relevant articles analyze applications design by using LBS (Espeter & Raubal 2009; Seiji, Katsumi & Nobuyuki 2001). Seiji Yokoji (Seiji, Katsumi & Nobuyuki 2001) report on how LBS is applied to searching documents on the internet. Martin, Espetera, and Raubal (Espeter & Raubal 2009) explain LBS use on a mobile device for finding a particular restaurant in a city by using validation to optimise the results of searching for the restaurant. These articles reveal a similar need to include a location-based search engine in the applications. The authors agree that it is a crucial "point to locate" feature for searching. According to Yokoji et al., a location-based search engine was developed for a searching algorithm based on the measure of a user-specified location and places that are described in web documents.

Espetera and Raubal describe the prototype used for validation of a location-based decision process aimed at searching for an optimal restaurant for a user group in an urban setting. However, their paper focuses on a search engine for restaurants only. A LBS approach applies with approaches of multi-criteria decision-making, time, geography and defining of a similarity measurement. LBS is developed to provide suggestions relevant to the user's social network (Weiss et al. 2015); the application is proposed to be capable of determining where people with similar taste would like to go, and to show the ranked recommendation. Moreover, Mobile Positioning Center (MPC) is presented by using cached location data from the mobile device and returns the location information to the domain name service (DNS) server, e.g. latitude and longitude (Haran, Saxena & Irizarry 2012). It can be adapted to a system which suggests useful places.

Yokoji et al. used latitude-longitude pairs to search documents on a mobile device. Their scheme consists of three modules: a module for documents collected from the internet, a module for analysis of text from web documents which can search latitude-longitude of the original text, and a retrieval module. In brief, LBS can be used with smart mobile devices to search and extract relevant detail.

Location within a geographically limited area is required for some places (homes, prisons, shopping malls, schools.) where an authority needs to know the physical location of someone (or an object) at any moment (Di Rienzo 2014). For instance, a teacher has many students in the school and she needs to know where each student is at any current time. If they walk outside an authentication area or into a danger zone, the beeper of the authentication system may alert the teacher. A PC monitor can show the pupil's position on the map by using a location device on the wrist of each student. For example, at shopping malls, the location device (beeper) identified by an ID number may be designed for temporary use for locating children. The device is programmed to respond to the child's location to a central server. If the parents would like to know the current position of their child, they can go to a PC and put in their child's ID number; it will send out a wireless signal to the child's location device and send information back to the computer and display the information for the parents.

The Quick Response Code (QR Code) Technology has also been adopted for the indoor LBS (Hakimpour & Zardiny 2014). In this research they designed a location-based system as a tourist guide for use in buildings such as museums, galleries or exhibitions.

Although this technique didn't need complicated hardware and software infrastructures, it is time-consuming to update the information on a regular basis.

The government of New South Wales has developed the NSW Location Intelligence (LI) strategy with the aim of using location intelligence in decision making, planning and service delivery for the benefit of the NSW Government, industry and communities (NSW_Government 2014). It will be applied in smart city environments deploying location-based information such as address, a postcode, and building. The strategy is adapted to types of business information such as financial data, service delivery data, and client information which can make intelligent choices and recommendations for users.

2.2 Indoor Navigation

People spend most of their time in indoor environments such as a university building, a department store, a museum, or their apartment (Dehghanzadeh, Ansarian & Aslani 2013; Jamali et al. 2015). The indoor navigation system has been developed for navigation inside a building. However, there is not a standard approach for the development of an indoor navigation system for a building because several techniques may apply and each method has both advantages and disadvantages. Some technologies can be better implemented for use in indoor locations.

Firstly, Bluetooth tracking can be used for an indoor positioning system with a mobile device (Hay & Harle 2009). Bluetooth receivers are set up in buildings where mobiles can access them as an IPS. However, achievement of a positioning system with Bluetooth means devices need to be fixed close together, and every point of the path needs to be clear to gain positional accuracy. An investment in Bluetooth devices to cover all areas in a building could be costly. Secondly, Radio Frequency Identification (RFID) may be used for locating objects in buildings (Ni et al. 2004). RFID devices can be used in two ways; either as active RFIDs or as passive RFIDs for use for indoor positioning systems. Passive RFID tags can respond with a code to the RFID scanner for positional analysis but may be limited in range. The authors point out that utilizing the concept of reference tags means using active RFID (Ni et al. 2004). However, once again an investment with active RFID tags may be too expensive for using them as an LMS. Thirdly, Global Positioning System

(GPS) is not efficient with an indoor location. Therefore, some other technologies are needed for indoor navigation such as RFID technology (Kourogi et al. 2006). They devised a method of GPS/RFID localization with self-contained navigation, which they applied using a Kalman filter framework with simple equations. Fourthly, Inertial Navigation System (INS) uses sensors which interact with a Wi-Fi positioning system (Evennou & Marx 2006; Fr et al. 2006; Lee et al. 2013). The wireless access point would help users detect their location in indoor environments where GPS technologies are inaccurate due to the signal weakness. The problem of Wi-Fi-based indoor localization is a user's mobile cannot normally connect to Wi-Fi access points to estimate the users current location. They designed a new algorithm for estimating locations with greater accuracy (Lee et al. 2013). Use of Wi-Fi and the camera in a mobile device have been applied as an indoor location estimation method (Hattori et al. 2009), but these techniques still need to use Wi-Fi base stations. Finally, Geomagnetic Positioning system, in principle, does not need any infrastructure for its application. However, such use requires a highly accurate map of the building's magnetic field (Xiaoying, Li & Tich Phuoc 2010). Magnetic sensors are already included in smartphones and should be simple to adapt for LMS use. This approach may well also be the cheapest and easiest method for LMS implementation inside a building, provided the magnetic field is static, which often is not the case.

A magnetic map was designed for multiple corridors inside a building which may be used for location tracking and indoor navigation by robots during an emergency or in a disaster situation characterised by poor lighting (Gozick et al. 2011). Storms et al. devised a vehicle navigation system for use inside a building (Storms, Shockley & Raquet 2010) using a real data map-matching scenario from magnetic data which had been previously collected. An array of e-compasses collected magnetic field data and compared these with a previously measured magnetic map from across multiple floors within two buildings. The positional accuracy results were claimed as 88% of the time (Chung et al. 2011). A Multiple Magnetometer Platform (MMP) was used for collecting and testing the magnetic fields inside a building (Afzal, Renaudin & Lachapelle 2010). This study had to identify and remove the perturbations in the magnetic field measurement. However, using the magnetic field for indoor positioning should look for a possible solution to affect the magnetic field measurement (Li et al. 2012), because it is very difficult to develop. The knowledge that researchers should understand on the indoor positioning includes Received Signal Strength Indication and Weighted Centroid Localization Algorithm.

2.2.1 Received Signal Strength Indication

Received Signal Strength (RSS) (Arun et al. ; Blumenthal et al. 2007) is signal which can measure the received signal between devices and is used for the calculation of position. Many localization algorithms require a distance measurement to estimate the position of unknown devices. One possibility to acquire a range measures the received signal strength of the incoming radio signal.

Received Signal Strength Indication (RSSI) (Adewumi, Djouani & Kurien 2013) is a standard feature in most wireless radios and has attracted a lot of attention in recent literature. RSSI is defined as the voltage measured by a receiver's received signal strength indicator (RSSI) circuit. Often, it is equivalently reported as measured power, i.e., the squared magnitude of the signal strength. It eliminates the need for additional hardware in small wireless devices and exhibits favorable properties with respect to power consumption, size and cost. Given a model of radio signal propagation in a building or other environment, RSSI can be used to estimate the distance from a transmitter to a receiver in order to estimate the positions of the sensor nodes. However, this approach requires detailed models of radio frequency (RF) propagation and does not account for variations in receiver sensitivity and orientation.

RSSI was presented as a probabilistic approach to the localization problem using only RSSI readings (Seshadri, Zaruba & Huber 2005), which almost all wireless devices are capable of measuring as a part of their standard operation. They have demonstrated the performance of the proposed approach through validation and real life experiments performed in an indoor environment with two access points. Their demonstrations show that even with all the required approximations, the system was successful at tracking the mobile node with a reasonable amount of precision, thus illustrating the potential of their approach in enabling location awareness among existing devices with no additional infrastructure.

2.2.2 Weighted Centroid Localization Algorithm

The Weighted Centroid Localization (WCL) algorithm (Blumenthal et al. 2007) is using the weighted arithmetic centroid to calculate the estimated position. The algorithm is obtained from a centroid determination which calculates the position of devices by averaging the coordinates of known reference points. Moreover, the Weighted Centroid Localization Algorithm (Liu, Jin & Cui 2010) is modified based on RSSI for WSN. Different from the former method, the sum of the reciprocal of each measured distance will be taken as the weight, instead of the mean of the total.

A paper (Wang et al. 2011) presents the first analytical framework for the performance of WCL for localization of PU transmitters in CR networks. They derived a closed-form expression for the error distribution of WCL parameterized by node density, node placement, shadowing variance, correlation distance, and errors in sensor nodes positions. Applying their theoretical results in conjunction with mathematical validations, the robustness of WCL against various physical conditions was investigated and quantified.

Anchor_optimized (Shi 2012) modified weighted centroid localization algorithm based on RSSI was proposed in their paper. In this algorithm, the localization accuracy is significantly improved by optimizing the anchor node and modifying the weights, which fully utilises the feature of the closer the distance measurement the higher the localization accuracy.

Furthermore, Weighted Centroid Localization algorithm (Fan et al. 2013) was applied for improving RSSI ranging, taking both the information of measured signal strength and the actual distance of all beacon nodes. The formula of the weighted centroid is an algorithm as follows:

$$X_e = \frac{\sum_{i=1}^{n} W_i \times x_i}{\sum_{i=1}^{n} W_i}, Y_e = \frac{\sum_{i=1}^{n} W_i \times y_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

Where

X_e is the estimated *X's* position of the unknown node.

Y_e is the estimated *Y's* position of the unknown node.

W_i is the weight of each fixed reference node.

X_i is *X's* position of the fixed beacon node.

Y_i is *Y's* position of the fixed beacon node.

In the networks, the position of the fixed beacon node B_i is known, which is $(x_i, y_j) 1 \leq i \leq n$. The estimated position of the unknown node M is (x_e, y_e), where W_i is the weight of each fixed reference node. Usually, the weight should be a function of the distance between the unknown node and the fixed reference node. If the unknown node can't communicate with the fixed reference node B_i, the value of W_i is 0.

When this formula (1) was used in their research, it resulted in a smaller positioning error and higher positioning accuracy in the distance measurements. It can help to improve the weighted arithmetic mean for validation, especially for indoor navigation development.

2.3 Internet of Things (IoT)

The "Internet of Things" (IoT) is the integration of the physical world with the Internet. It is the deployment and exchange of global Internet-based information with "smart objects" (Kopetz 2011; Ronen & Shamir 2016; Weber & Weber 2010; Xia et al. 2012), which have embedded systems connecting them to the Internet. The Internet of Things allows communication between different forms of smart devices, expanding from human-human interaction to human-human, human-things and things-things (Tan & Wang 2010); every object can be connected. Location-sensing technologies are essential technologies for tagging, tracking, locating and monitoring and producing a massive repository of data (Wang 2015). A Location-Based Service (LBS) applies to knowledge of the current position of a mobile device obtained by using various devices and technologies (Chung et al. 2011; Newman 2014; Sterling 2014; Zàruba et al. 2007; Zipf & Jöst 2011) for navigation. Currently, indoor navigation has no standard devices. Modern smartphones now have built-in sensors, including accelerometers, light-sensors, magnetometers, ultrasound, Bluetooth, which allow the development of mobile applications for location determination.

Moreover, many smart devices are applied to any systems for IoT technology (Biswas & Giaffreda 2014; Kelly, Suryadevara & Mukhopadhyay 2013; Lin et al. 2015; Ronen & Shamir 2016). For example, wireless-sensors, RFID and actuators are increasingly integrated into new value-added applications of the Internet and are intelligently joined using standardized software services (Meyer, Ruppen & Magerkurth 2013). The relationship between all these terms of IoTs is schematically summarized in Figure 2.1: the device monitors the thing in the environment, or some devices can be embedded and attached to them. As described in the figure, classes of devices can be applied to looking for interesting things, hence the subclass relationship. Services accessed through to device hosts may be one or more devices types.

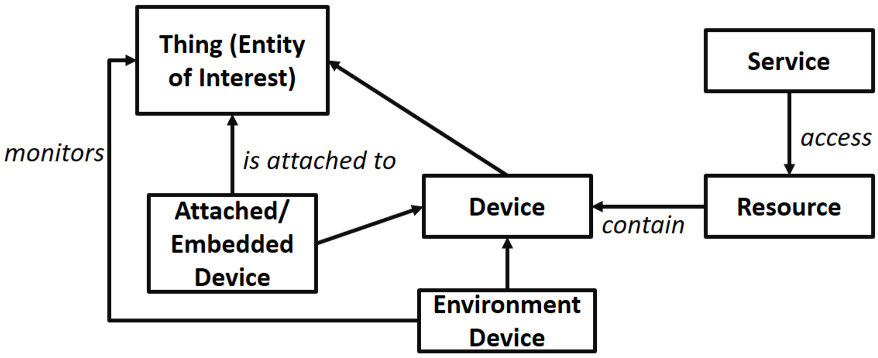


Figure 2.1. Relationship of IoT technology includes devices, resources and services (Haller 2010)

IoT was identified and integrated (Meyer, Ruppen & Magerkurth 2013) to improve this situation considerably with a new extension to standard process modeling methods. IoT devices have introduced a process resource type to the traditional ERP systems in the business process for supporting a BPM lifecycle. It had demonstrated the purpose of the new resource type and had extended the three layers of the process metamodel with the standard BPMN 2.0 notation.

Therefore IoT is a part of the development of the smart city; selecting the device for the suitable mission can support the city to be an efficient system for its inhabitants. However, the developer should select the smart devices to apply to IoT development for suitable solutions.

2.4 Ontology

Ontology is a set of names and description of the types, properties, and interrelationships of the entities. Ontology has the structure of a dynamic database, which is efficient for LBS searching development (Maedche 2012). The ontology can be developed using Web Ontology Language (OWL) (Bechhofer 2009). Ontology techniques have led to an ontology framework for indoor navigation systems such as indoorGML and BIGML (Kessel, Ruppel & Gschwandtner 2010; Kim, Yoo & Li 2014), which focus on the representation of indoor spaces.

Ontologies have techniques in common with a Semantic Database. There are three fundamental requirements for a fully functioning semantic database: dictionary encoding, RDFS inference and query processing. Ontologies in computer systems have three models (Lim 2011): top-level ontologies, lexical ontologies, and domain ontologies. This review will compare applications of different methods for the domain ontology, using a different reasoning of knowledge to make the decision.

2.4.1 Top-level Ontology

Top-level ontology, also known as upper ontology, is not a particular domain, but it allows a domain ontology to be constructed. It can support data interoperability, semantic information retrieval, automated reasoning and Natural Language Processing (NLP).

Most current research on ontology includes using a top-level ontology model (Vogt et al. 2012; Ye, Stevenson & Dobson 2011). The authors discuss how top-level ontology is promoted for the capture of domain knowledge in recognising human activities for use in a smart house (Ye, Stevenson & Dobson 2011). They argue that the common semantics provides information at different levels for supporting communication, reuse and sharing of ontology between systems, where it should be able to understand the meaning from sensor data. It can be deployed for setting up the technology for a smart home in the real world. However, the authors propose a new method in the top-level ontology (Vogt et al. 2012), the basic formal ontology (BFO), which is designed for use in the biomedical domain (Vogt et al. 2012). The authors explain that their purpose is to support an ontologically consistent template for top-level categories for their application. They applied this approach to journals in the computer and health science areas and described that the similarity between journals as the number of authors who have publications in journals with high reputation and low reputation. Although the idea presented by Vogt et al. makes sense and is simple, it is difficult to use for developing an application, where the performance depends on the form of the algorithm. It means that if the algorithm has a good design, it will be highly effective.

While there is much research using a top-level ontology derived from a variety of sources, social networks are areas which have adopted using upper ontology (Grabarske & Heutelbeck 2012). They describe how both social relations and institutional rules are represented by General Social Ontology (GSO) (Grabarske & Heutelbeck 2012), which can help to encode simple rules and can be mapped to each other for integrating a rules and policy engine. However, other researchers present the fundamental concepts of the Upper Ontology of Culture (UOC) with the discussion in organizations for the development of culture-driven automatic reasoning processes (Blanchard, Mizoguchi & Lajoie 2010). They detail how theory-driven and interdisciplinary conceptualization can support the computerisation of cultural data before development for finding the reason processing and designing the application. They applied their method for developing an upper ontology which included the cultural issues.

2.4.2 Lexical Ontology

A lexical Ontology defines the word meaning using an ontological structure. An example of lexical ontologies includes WordNet and HowNet. Wordnet is based only on the English language, and HowNet is developed for Chinese-English (Lim 2011). This approach is concerned with developing a knowledge-based system which has text analysis and a dictionary.

There are two papers which describe use of a lexical ontology (Boudabous, Belguith & Sadat 2013; Krizhanovsky & Smirnov 2013). Boudabous and Belguith propose a method to make a lexical ontology for the Arabic language (Boudabous, Belguith & Sadat

2013). They built phases of the primary ontology which is implemented via the Tool for Building Arabic Ontology system (TBAO), and developed an ontology with about 200,000 concepts in their research (Boudabous, Belguith & Sadat 2013). Like Krizhanovsky and Smirnov, they detail how to use a lexical ontology for developing a dictionary. Their paper presents a design for a lexical ontology for Russian and English Wiktionaries (Krizhanovsky & Smirnov 2013). In contrast, Boudabous and Belguith (2013) describe the building of an Arabic lexical ontology from Wikipedia articles.

2.4.3 Domain Ontology

Domain ontology is developed for a specific domain from upper ontology, developed from the concept formation in the important domain of interest. It is preferably built based on an available top-level ontology for mapping and integration between different domain ontologies (Lim 2011).

According to Lim et al., a domain ontology is related to a particular domain which can be extended from the upper ontology (Lim 2011). A domain ontology is acquired under the concept formation in the specific domain of interest. Particular meanings of terms applied to a particular domain are provided by domain ontology. Domain ontology is based on top-level ontology (e.g. SUMO, Cyc) for mapping and integration.

Moreover, Lim et al. assert that the domain ontology graphs (DOG) are a new ontology learning model (2011, p. 103). There are two critical components in the DOG, specifically the definition of the ontology graph and the ontology learning process (Liu et al. 2014; Liu et al. 2013). The authors maintained that as a result of the experiment they could produce significantly better classification accuracy when compared with other methods. They point out that a well-constructed ontology can be efficiently developed for the application developments such as the web search engine system. However, they focused on only Chinese language, and there is a need for more techniques for applying to other languages.

The DOG approach is applied in their paper; it is a semi-automatic process which includes both manual and automatic processing. The manual processes include defining the term list, word functions and clustering label which can be obtained from the dictionary. The automatic processes include the domain term extraction, term relations extraction and concept extraction which is a taxonomical and semantic relationship.

2.5 Ontology with Indoor Navigation

Ontology is applied to many indoor navigation models. Wang et al. designed an ontology for representing a semantic location in indoor navigation models. The semantic information and multilayer semantic locations were presented with the ontology, which consists of two types of information: *static information* such as the structure of the room, and *dynamic information* such as the sensing areas. However, this ontology is limited to a map of only one floor, and is not linked to the other levels in the multi-floor building. OntoNav is a hybrid modeling technique (Tsetsos et al. 2006) which develops geometric and semantic information for user navigation. The ontology OntoNav addresses the linking of other floors in a building; users need to select the path rule for traveling, and the restriction of the route may be difficult for maintenance. A color Petri Net model (CPN) using an RDF format for ontology has been developed for an indoor location-based system (Yim, Joo & Lee 2012). Their model can identify the properties of core classes (such as subject, predicate, and object onto places), and map these properties onto CPN places. Scholz, J. and Schabus, S. adopted an ontology to support autonomous indoor navigation in the production environment (Scholz & Schabus 2014). Their research used RFID and ultrasound technology to support autonomous navigation in the indoor space and develop a tracking system called *LotTrack*. However, the installation of RFID in buildings is potentially a large investment. Another approach for an indoor location used a Genetic Algorithm (GA) and a neural network (Chen et al. 2015) to collect positional data using RFID tags, RSS information, and four reader devices. Their research was limited in scope, covering only one level. The researchers applied the ontology with an indoor system to assist indoor shopping by localizing shoppers and suggest on where to find suitable offerings related to products that customers need (Orciuoli, Parente & Computing 2017). This model should use more customer information to improve intelligence recommendations for the indoor navigation for shoppers.

2.6 Modularization of Ontology

The domain in the ontology should be reusable in the same domain for other applications. The modular design is an advantage to both ontology development and the reuse for other applications.

The modular design uses inheritance of upper ontologies describing common knowledge, and application ontologies detailing knowledge for a particular application, as shown in Figure 2.2 below (Obitko 2006). Depending on the scope of the ontology, an ontology may be classified as follows:

- Upper, generic, top-level ontology - describing general knowledge, such as what is time and what is space.
- Domain ontology - describing a domain, such as medical domain, electrical engineering domain or narrower domains; such as a personal computer domain
- Task ontology suitable for a particular task, such as assembling parts.
- Application ontology developed for a particular application, such as assembling personal computers.

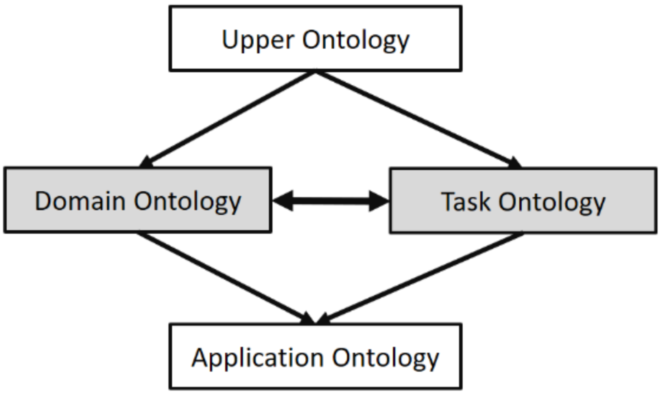


Figure 2.2. Modularization of ontologies depending on the scope and partial ordering defined by inheritance (Obitko 2006)

At each level, modularization can also be applied; for instance, upper ontology may include modules for real numbers, area name, time, and space where these parts of the upper ontology are usually called generic ontology. Ontology at lower levels import ontology from high levels and add additional specific knowledge. In this way, ontologies form a lattice of ontologies defined by the partial ordering of inheritance of ontology. Task and domain ontologies may be independent and are joined for application ontology. For example, task ontology uses domain ontology. The upper ontology is the most reused, while application ontologies may be suitable for one application only.

When developing a new ontology, it is desirable to reuse existing ontology as much as possible. The new ontology should be started by importing upper-level ontologies when an appropriate ontology exists. This technique will simplify the development, since one can focus on the domain or application particular knowledge only. It will also streamline integration between applications in the future since defined parts of ontologies will be shared.

2.6.1 Domain Ontology

Domain ontology is proposed as the class diagram; Zouaq et al. have described the field of domain ontology engineering (Zouaq & Nkambou 2010), focusing on ontology learning techniques and highlighting how Intelligent Tutoring Systems (ITS) may benefit from this ontology engineering. One of the main advantages of this engineering is that it can provide a solution to two issues: first, the difficulty of building an ITS domain model from scratch for each domain and second, the difficulty of sharing and reusing the available representations. As standard knowledge representations, ontologies can support the ITS community in producing ITS components more easily and at lower costs. However, this involves the availability of a unified framework for the entire ontology lifecycle, including ontology learning, evolution, alignment, matching, and evaluation.

The method for solicitation requirement has used ontology (Kaiya & Saeki 2006). The method helps a requirements analyst to extend requirements systematically by taking account of the semantic aspect of the requirements. They define logical structures of artifacts during the process and its procedure. In the process, the following two kinds of activities are iterated; evaluation of requirements by using quality metrics, and revision of the requirements based on the structural characteristics in the ontology. They partially assess the user-friendliness and effectiveness of this method through an experiment. However, their experiment was too small to argue the generality of the technique.

2.6.2 Task Ontology

This ontology will be proposed in the activity diagram. Task ontology was applied to tourism activities such as a task model based on travelers' perspectives using traveler's needs and activities (Park, Yoon & Kwon 2012), and this task ontology uses the task model for intelligent tourist information services. The task ontology model (Yuan & Liu 2012) has been used to create a task ontology for two tasks from different domains. Based on the model and the modified dialogue manager, a dialogue system has been developed and experimented with the two tasks.

Task-ontology-based Task-Oriented Tourist Information System (TOTIS) was proposed for various travelers' activities and viewpoints (Park 2013). The TOTIS can provide a task-oriented menu for discerning tourist information services using the concepts, instances, properties, and relations of task ontology according to various travelers' needs and activities. On the other hand, the domain-oriented menu using domain ontology is constructed from the system's perspective. The TOTIS provides for a more intelligent tourist information service than the existing methods. It can be described as a novel ontology-based smart tourist information service model centered on travelers' needs. In the model, travelers can efficiently plan, and enjoy, interactive tour services in ubiquitous environments.

2.7 Summary

This chapter reviewed existing literature on theories and models related to indoor navigation. The main purpose of the literature review is to find gaps in the theory in the literature of indoor navigation. After the literature review was conducted, it become clear that there is no ontology in domain ontology for indoor navigation for a multi-level indoor environment. Ontology definitions were introduced for some existing indoor navigation. Semantic location in an indoor navigation model uses static information and dynamic information, but this model applies to a map only on one floor inside the building. In this thesis, the data of the building will be put on the node for supporting the navigation. This information can help to improve the indoor navigation system on mobile, especially the dynamic information which can lead to updating the route in real time.

The *OntoNav* model uses an approach to link other floors in the building; users need to select the path rule for traveling, and the restriction of the route may be difficult for maintenance system. This approach will be adapted to use in this thesis, which links to the different floors of the building; these will be applied with nodes. All nodes have the location information which is necessary to connect to the different levels of the building or area zones and can develop to many situations in a high-rise building.

LotTrack used RFID and ultrasound technology to support autonomous navigation in the indoor space and developed a tracking system. RFID in buildings will be a massive investment. Therefore, other devices may be needed to support indoor navigation, of which Bluetooth devices are chosen as the tool for helping the indoor navigation system in this thesis.

From the literature reviewed, previous ontology designs have not been used for vertically and horizontally linking inside a multi-level building using indoor localization information. No emergency situation was considered in the ontology design. This thesis improves on earlier designs and presents an ontology design for multi-level indoor navigation. The new ontology will classify an indoor environment to attributes such as nodes, zone, link and route array. It can lead to an exchange of position data between all nodes and can apply to the model for a semantic property of indoor navigation. In addition to the multi-layered space, it can link a unit of a map node to the semantic description. The multi-level indoor navigation algorithm is developed for validation for use with smart phones.

A new ontology suitable for use in a multi-level indoor environment will be developed in this theis to contribute to the indoor navigation ontology domain.

Chapter 3
Development of Multi-level Indoor Navigation Ontology for Location-based Service

This chapter presents an Indoor Navigation Ontology Model for Location-Based Services (LBS). It starts with the introduction, describes the LBS navigation process for users, details the architectural design of the ontology and presents an ontology design and applied Indoor Navigation Ontology model.

3.1 Introduction

Currently, indoor navigation does not have a standard approach; it needs to be applied with some technology. The ontology developed in this chapter models the indoor environment to classes of nodes, link, route, status, building status, emergency situation and normal situation. The ontology describes the nodes for an indoor navigation search under both normal and emergency situations. The model is designed to provide indoor localization information, which is compatible with the combination of Bluetooth devices, to determine the user's current position. This ontology model contributes to a new standard for indoor localization information for LBS indoor navigation. Indoor navigation is one of the functions for LBS with high assurance. As well as working under normal situations, the LBS should still work in emergencies. The LBS should be able to assist users to find the best exit route to the outside of a multiple level office building, shopping mall. under all circumstances with high reliability.

In this chapter, an Indoor Navigation Ontology Model will be presented as a Multi-Level Indoor Navigation Ontology. Indoor information is vital for the development of indoor navigation applications to enable the user to join their current position to other levels of the building and navigate between them.

3.2 Location-based Service of Indoor Navigation Process

Figure 3.1 shows the processing of indoor navigation between user and LBS, using a three-step navigation process flow for users (Sterling 2014): (a) *Indoor Positioning,* (b) *Geofencing*, and (c) *Way-finding*.

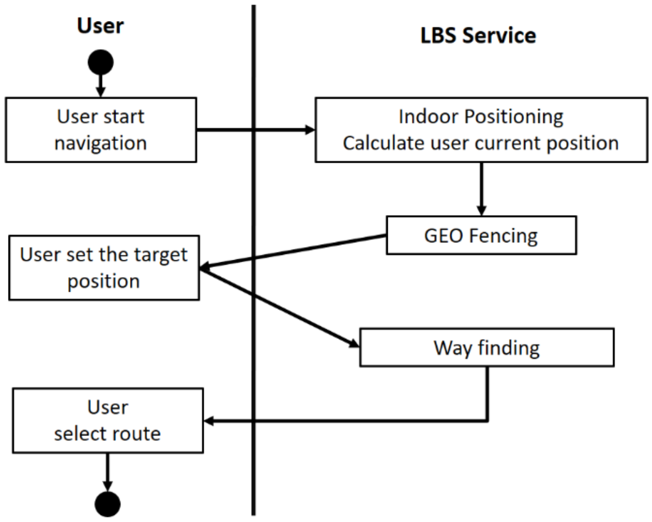


Figure 3.1. The overview of the indoor navigation process

a). Indoor positioning - Calculating the user's current position and displaying the current position on a smartphone as a "*Blue dot*" on a digital map. This step needs at least three Bluetooth devices for analysis.

b). Geo-fencing - Defining a virtual boundary around a real geographical area. A radius of interest is established that can trigger an action in a geo-enabled smartphone. The names of the places within the radius are visible to the users while some areas may not be visible to some user.

c). Way-finding – Finding the optimal route to a destination of interest, and displaying the direction to the target of interest. This design proposes regular routes and emergency routes for high assurance LBS.

The ontology is designed to provide indoor location information for this user's navigation process.

3.3 Architectural Design of the Ontology

The architecture of the Multi-Level Indoor Navigation Ontology is designed using a UML diagram as in Figure 3.2.

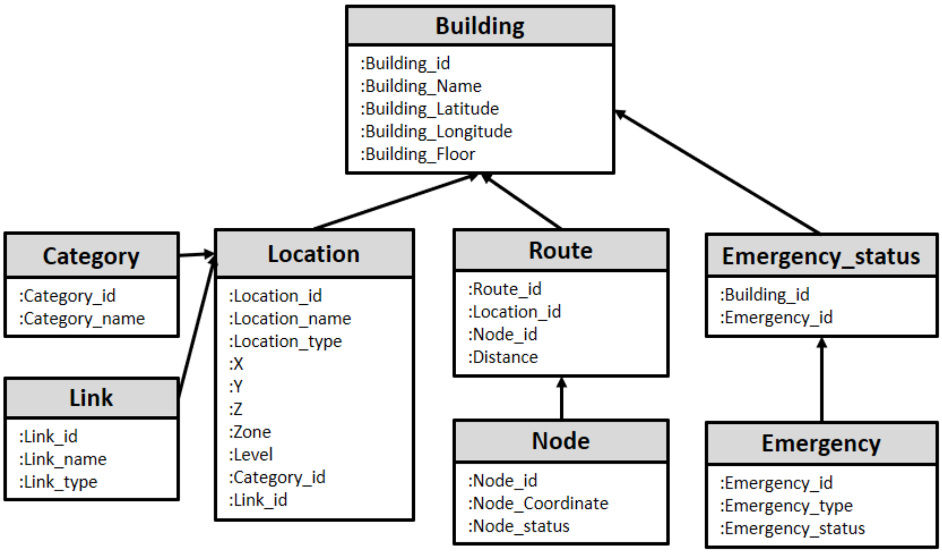


Figure 3.2. Multi-Level Indoor Navigation Ontology

The ontology is designed using classes and associated attributes. The major classes are: "*Building*", "*Location*", "*Route*", "*Link*", "*Catrgory*", "*Node*", "*Emergency*" and "*Emergency_Status*". All classes are used for development of the indoor navigation model. The major classes are designed as follows.

Building: Building is the main class for user navigation. This class present the building information. The attributes of *"Building"* include *building ID, building name, the number of the floor of the building, building latitude and building longitude*.

Table 3.1. Attributes of building class

Attribute	Description	Type	Example
Building_ID	ID of the building	Text	BLD610520001
Building_name	Name of the building	Text	Building 11
Building_floor	The total number of floors of the building	Number	12
Building_latitude	Latitude of building	Number	-33.8839751
Building_longitude	Longtitude of building	Number	151.1967971

Location: This is the class to define the physical area of an object. In this ontology we use *'node'* to identify three types of area*:* Place Location node *(Place_Location),* the user mobile location node (*Mobile_Location*), and User Device Location node (*Device_Location).* The details of the location types and nodes will be described in the next section.

Table 3.2. Attributes of location

Attribute	Description	Type	Example
Location_ID	ID of location in the building	Text	SC04006, Room04202
Location _name	Name of location in the building	Text	Room04204, Men's toilet 1
Location_type	Type of location in the building such as coordinate space (1), place location (2), mobile location (3), or device location (4)	Text	2, 4
x	Value of *x position* on the map	Number	251, 675
y	Value of *y position* on the map	Number	540, 641
z	Value of *z position* on the map	Number	255
Zone	Zone is a continuous area in one building which is characterized by building management	Text	Zone0403, Zone0602
Level	Level of the building	Text	Lev4, Lev5
Catgory_id	Catgory ID location	Text	CT01, CT03
Link_id	Link ID which links to different floor	Text	Link0402

Node: Node is the class to define the information for the place. Node classes are used to create the routes on the array and applied to showing the route on the map. Node has attributes of *Node ID, Node coordinate,* and *Node Status*. It is used to create the route on the array. These attributes are defined in Table 3.3, and show the physical nodes and links in a building.

Table 3.3. Attributes of node class

Attribute	Description	Type	Example
Node_ID	Node ID	Text	N001
Node_coordinate	Coordinate name	Text	SC01
Node_status	Node status	Text	1

Category is a class to define the group of places or connection on the digital map for LBS services. The category is used to help to develop the LBS indoor navigation system with different types of services such as in education or a department store. For example, the groups of a searching category could be shop, immigration agency, meeting room, and classroom. The attributes of "Category" are *category ID*, and *category name*.

Table 3.4. Attributes of category class

Attribute	Description	Type	Example
Category_id	Category ID	Text	CT01
Category_name	Category Name	Text	Shop

Route: Route is a class to define the way for a user to navigate from a starting location to the destination. The route class has "*Location*" and "*Link*". The link will be defined next. In our ontology, we define two types of routes for indoor user navigation: *Emergency_Route* and *Normal_Route.* These two types of routes are determined by the status of the building situation. The attributes of the *Route* class is designed using *Route ID*, *Location ID, Node_ID* and *Distance.*

Table 3.5. Attributes of route class

Attribute	Description	Type	Example
Route_ID	Route ID	Text	R170114, R170102
Location_ID	Location ID	Text	Room040201, Room050204

Node_ID	Node ID	Text	SC042153, SC062001
Distance	Value of distance	Number	1.520, 2.431

Link: Link is a class to define the connection from a node to a different floor of the building vertically. *Link* has the attributes of *Link ID* and *Link Type*. This is necessary to show the direction of the connection between the floors of the building because it has to be connected in many ways, including stairs, escalators or elevators. Some connections may have a repair status. Therefore, the route will be closed, and the system can suggest other routes

Table 3.6. Attributes of link class

Attribute	Description	Type	Example
Link_ID	Link ID	Text	LK05002
Link_name	Link name	Text	Lifts01
Link_type	Link type	Text	1, 2, 3

Some of the attributes used in our ontology are described in Table 3.7. The detailed design of this ontology is described in the next section.

Table 3.7 Terminologies for Some Attributes in Ontology

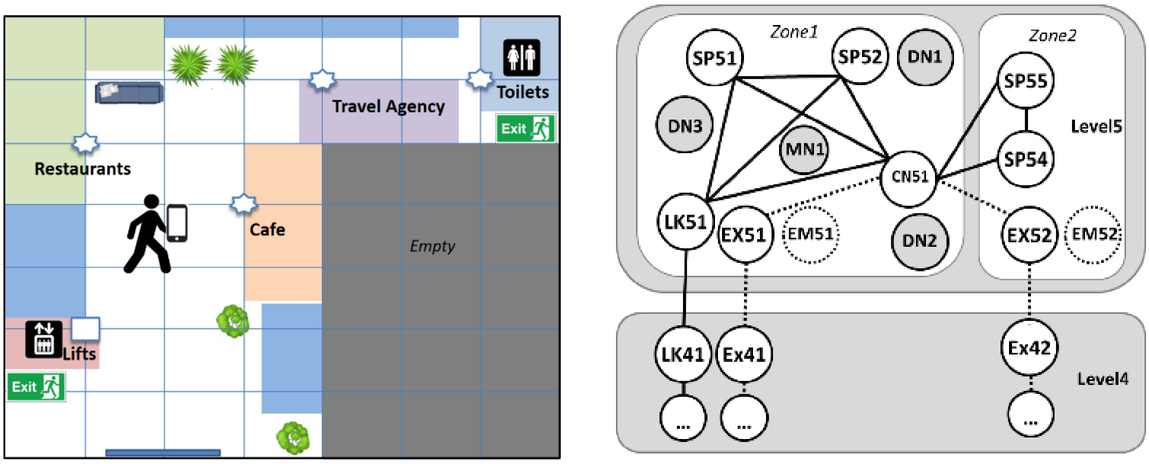
Terminology	Definition	Example
ID	ID is a unique label for a Node, Link, Route, or a Zone	L51-Nd2_0001 (Level 5, Node 2, 001)
Coordinate system	The coordinate system is defined in 3 dimensions, two horizontal and one vertical.	(0,0,0) can be defined at one entry location of a building.
Coordinate	(X, Y, Z) in Euclidean space	(23.45, 47.81, 4.00)
Place_name	Place name or all connected nodes in the building	Café, Room 11.04
Level	The floor number of a building	L5: Level 5

Zone	A zone is an area specified on the Map Sheet. Some places are small and are not a room. They have a sofa and a small table; they may be the meeting point for someone.	Zone51 (Zone 1 on level 5)
Category	The category is the type of place selected for display for users in the mobile application.	Shop, Service, Toilet, etc.
Status	Node has status over time and situation.	*On* is working and *Off* is not working.

3.4 Detailed Design of the Ontology

Developing the "nodes" is required to design the ontology at a detailed level for the indoor navigation system. Figure 3.3 illustrates the digital map in a building and the nodes and links concepts from the ontology.

The primary contribution of our ontology is a new node property. We designed three types of nodes: *Location-Node* to represent a physical indoor location in a building, *User-Mobile-Node* to represent the user dynamic location and *Device Node* to describe the device location. These nodes are designed as follows.



(a) (b)

Figure 3.3. Concept of node (a) map and nodes (b) nodes and links

1) Mobile Location Node

In our design, the location of a user carrying a smartphone will be assigned an active node or blue dot, called "*User-Mobile Node*" (MN). This is a dynamic node. The attributes of MN will allow calculation of the current position.

2) Device Location Node

Device Node (DN) is designed for calculating the current user location. The devices can get measurements for location calculation.

3) Place Location Node

Each node, such as shops (SP), is designed to connect with others and use the *connection* (CN) for connecting to a zone area on the same floor. The building may have more than one level. The nodes should be able to link to other levels. *Link* is some way of going to other levels of the building. For example, as illustrated in Figure 3.3, this thesis uses the *Link* (LK), such as LK5 on Level 5 of the building, to connect to LK4 on Level 4 . There may be different choices for the route, such as using an elevator or an escalator to connect to another level. The order of the nodes is the direction of travel between floors in the building. Therefore, two Link nodes can tell the direction of travel between the floors. For example, (LK5, LK4) is travelling from level 5 to Level 4 or (LK4, LK5) is travelling from Level 4 to level 5. Using CN or LK can improve the processing efficiency. This research designs a status concept for each node. The status of the node assists in the recommendation of the route for real-time indoor navigation.

The multi-level information nodes show how to connect all nodes together on the vertical layer information. Our research designs a "Map Sheet" to include Links and Zones. *Links* and *Zones* are the connection points to connect to other levels and areas. A route array will be created when a user requests a way-finding search as shown on Figure 3.4.

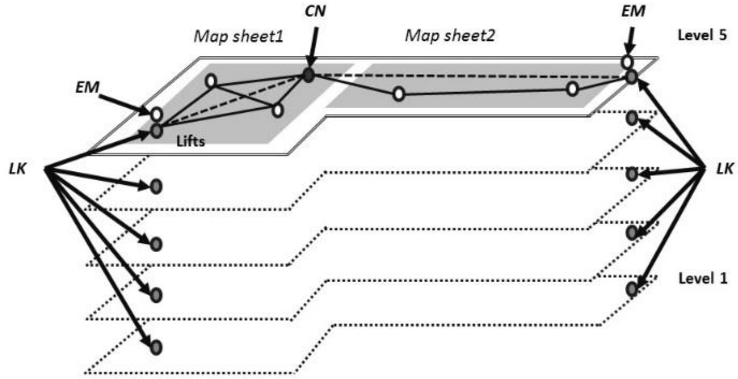


Figure 3.4. Map sheet and connection to different levels of the building

This work defines a "*Zone*" in the building digital map at all building levels. Map sheet builders can divide a floor into different zones for efficient management.

3.5 Applying Indoor Navigation Ontology Model to LBS

This ontology can be applied to indoor navigation for LBS using three steps which flow from industry practice: Indoor Positioning, Geo-Fencing and Way-Finding (Sterling 2014). In Figure 3.5, this is shown in more detail than in Figure 3.3. It shows the concept of the algorithms which are used to develop the indoor navigation application. Firstly, the user uses the mobile app, for which the algorithm will calculate the user's current position in the building. After that, the algorithm will be applied to get the places or rooms in the tower and shows the rooms which are nearby the user on the smartphone. Users select their destinations and then the application will analyze the best route for giving the user directions applicable to either the regular route or the emergency route.

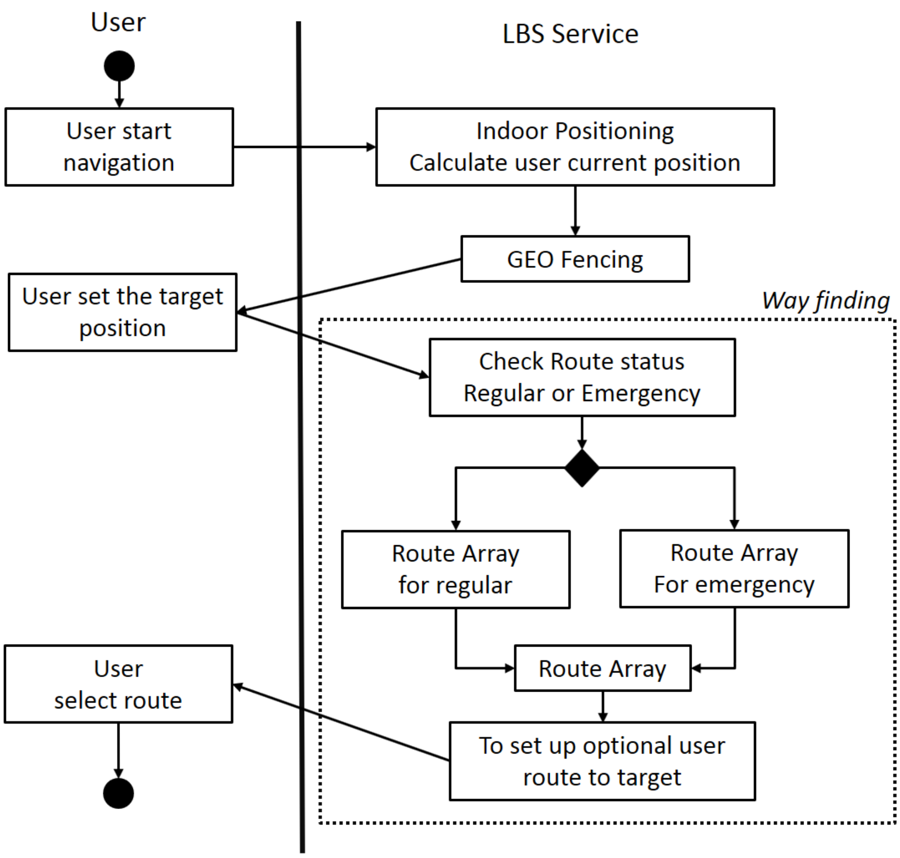


Figure 3.5. Algorithm of Multi-Level Indoor Navigation Ontology

Step 1: Indoor Positioning

Figure 3.5 shows the concepts of indoor positioning using ontology. The indoor positioning is the first of step for the indoor navigation, the concept of which is explained in Figure 3.6. The building may have many levels; Bluetooth devices used as nodes will be set up in the building for supporting the calculation of a user position. A user can use the devices deployed at a nearby Device Location node (DL) together with the smartphone sensors at the user's Mobile Location node (ML) to obtain the location measurements and compute the user positioning information. Place Location node (PL) is the destination for way-finding in a later step. Data from all nodes is crucial in this research; it will be used for supporting the indoor navigation system.

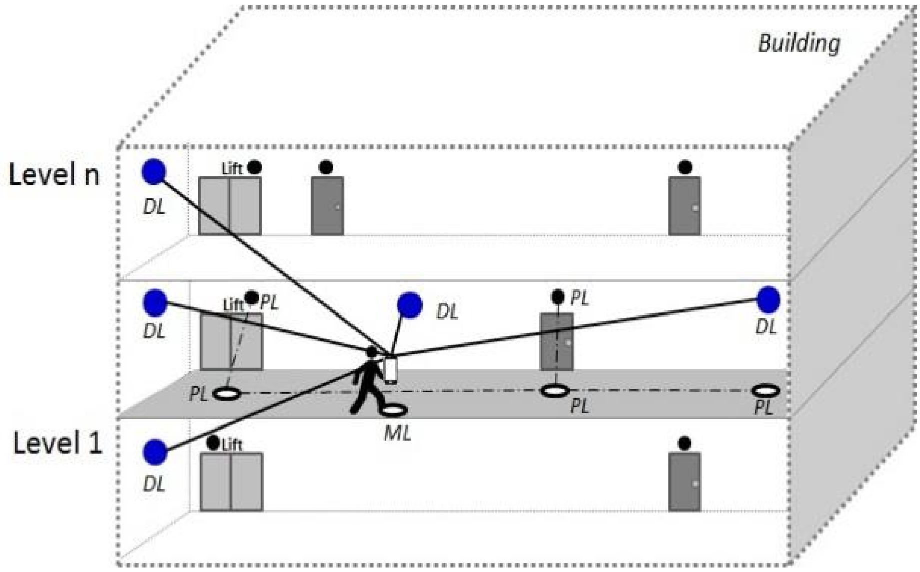


Figure 3.6. Indoor positioning using device location and user mobile location

The status "On/Off" is designed to be assigned to all nodes. The status will be applied in different situations for the building. If the status of one node is set to 'Off' in an emergency situation, the indoor positioning will use the nearby node which is set to 'On' status for an emergency.

Calculating the current position, where the user is inside the building or while using the mobile for finding a particular route, requires at least three devices nodes. These three devices nodes are set at the locations on the map as shown in Figure 3.7. These devices nodes include *BLE0401, BLE0402,* and *BLE0403,* and are used to get the distance from the user's mobile. The algorithm will use these distance for calculating the current position on the map with the RSSI signal of all sensors, for analysing the node. This mobile's current position on the map is used to find the next step of the route.

All coordinates are set the values which include x, y, z for using the 3D position inside the building. This research calculates the mobile position by using information from at least three nearby nodes before applying it in the indoor navigation application. The mobile will use information which it obtains from the Bluetooth devices. They are located in positions setup in the ontology to calculate the current position.

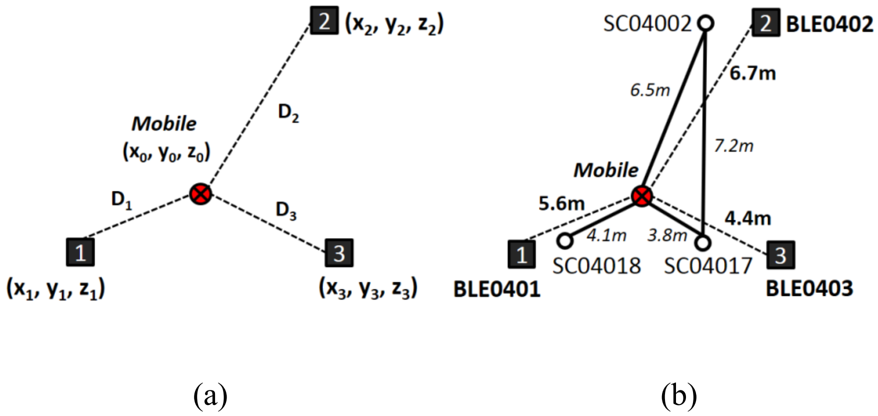


Figure 3.7. Process to compute the mobile node position

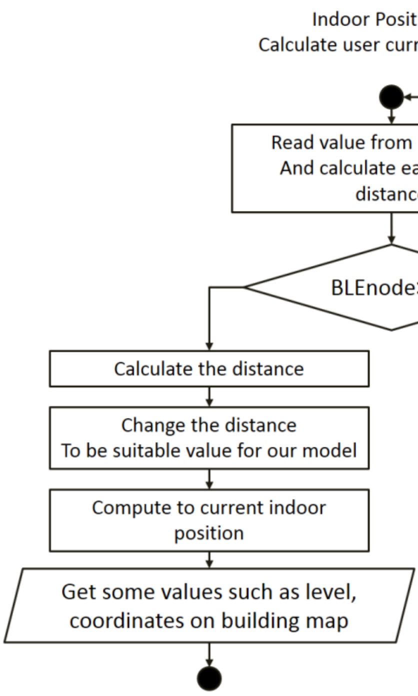


Figure 3.8. Algorithm for calculating the mobile node position

The route can be analysed by the algorithm. This thesis found that the calculation of the current position of the user is an important part of the algorithm, because it affects the distance of the route to the target for the indoor navigation system for both regular route or emergency route.

This thesis uses the formula from (Dong & Dargie 2012) for distance calculation as in Equation 2.

$$RSSI = (10 \times n) \log_{10}(d) A \qquad (2)$$

where RSSI is the radio signal strength indication, n is the signal distribution constant, d is the distance between the communicating nodes, and A is a reference taken signal strength in dBm which the RSSI value contained the separation distance between the receiver and the transmitter.

Therefore calculating distance:

$$RSSI = TxPower - 10 \times n \times \log(d)$$

n = 2 (usually 2 or 4 in free space)

$$d = 10^{(\frac{TxPower - RSSI}{10 \times n})}$$

which gives the following distance (n=2):

$$d = 10^{(\frac{TxPower - RSSI}{20})}$$

where,

d is Distance between sender and receiver

$RSSI$ is Received Signal Strength Indicator

$TxPower$ is Transmission power level of the sender

This formula will be used for validation, for calculating the distance from each beacon position. In the algorithm, each distance is used for estimation of the mobile position in the building. In the coding for the mobile application, the distance will be found using the function below.

```
double getDistance(int rssi, int txPower) {
    return Math.pow(10d, ((double) txPower - rssi) / (10 * 2));
}
```

Step 2: Geo-fencing

After getting the current position, the user can select the destination on the mobile application. This section explains how the algorithm displays the places in a given area which relate to the user's current position. Once the user's current position is determined, the LBS navigation system will display the places ($PLnode_i$) within a designed zone area. The process starts with obtaining the user position, after which it will check the coordinate status (on/off) on the corridor, before showing the rooms or places for selection.

The status tells the algorithm how to select the regular or emergency route. Moreover the status can also provide information on where no access is recommended for reasons such as way closed, room closed, or room is under repair. The status of the nodes may affect the path recommended for the user.

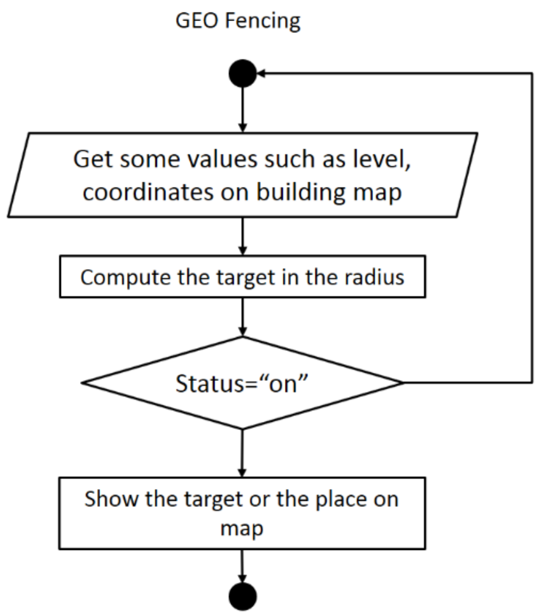


Figure 3.9. Geo-fencing process

When the user selects the target, the node information will be sent to the next step of the process for analyzing the way-finding.

Step 3: Way-Finding

The *Route* class in ontology will be applied in way-finding using route array design. The coordinate node on the corridors will be put in the route array for navigation to a target. The format of the array like *Route_Array[size]* in which *size* is the number of members including $LK_1, SP_1, CN_1 \ldots LK_i, SP_i, CN_i$, is an example to connect Link (LK) and Shops (SP) and Connections (CN). The value in arrays are node name on the route. The best route will be presented to the user while they use the application on mobile with start point or current position in the building.

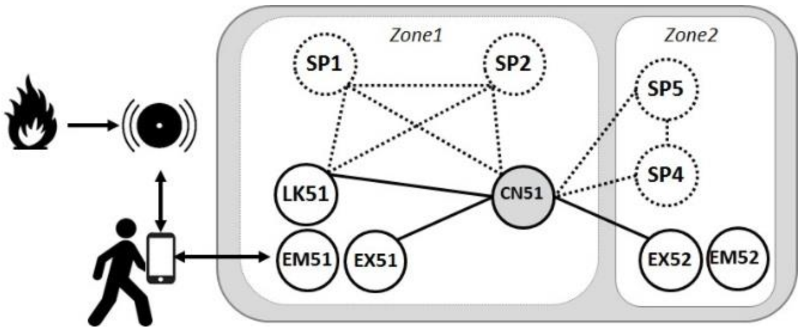


Figure 3.10. Nodes and links on the emergency

Figure 3.10 shows the application when a fire alarm turns on; the associated sensor on a smartphone will use the status of location nodes for analysing the emergency route. For the route that user can travel, the node status is *"On"*. While the status of some nodes will be changed to *"Off"* for updating the normal route. When the building has an emergency, then the emergency nodes will be changed to *"On"*. The indoor navigation system is switched to emergency mode and displays the emergency route to users.

For a high assurance LBS, two types of routes are considered: *Regular Route* and *Emergency Route* using the node status.

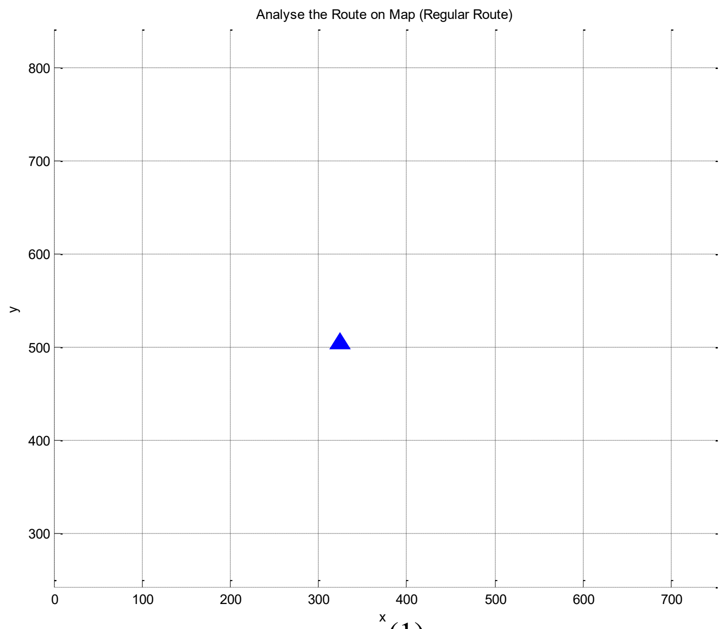
1) *Regular Route*: Most of the time, the building is in a normal status without any special situations such as being under fire alarm or attack. The LBS map will display the regular route using the way-finding algorithm for selecting nodes whose status are set to "*On*".

2) *Emergency Route*: When the building is in an emergency situation, or some location nodes are in maintenance, these location nodes are set to "*Off*". We will find other nodes for calculating the current position from the remaining device nodes.

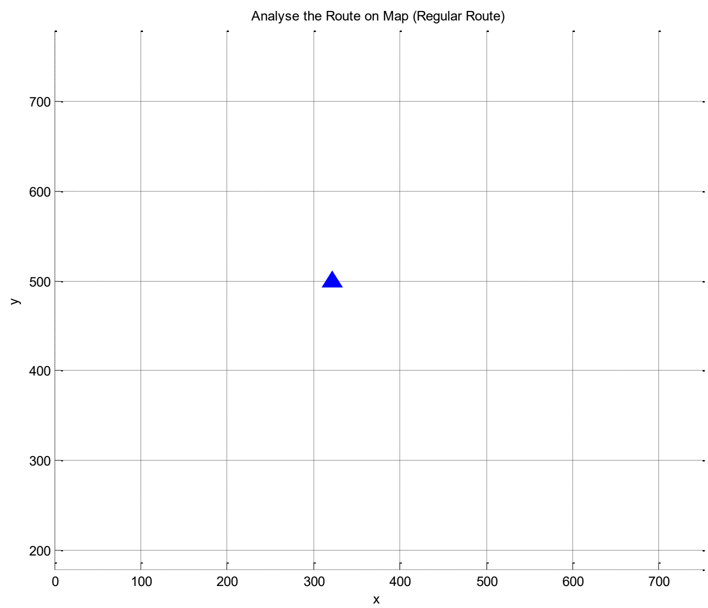
When the process is validated by an experiment the node stutus can be used in every step of the algorithm as indicated below.

3.5.1 Current position

This step is an analysis of the current position, which begins with the distance calculation from each iBeacon node and the mobile node. The result of current position may be different every time as it relates to the distance value which the mobile collects from the BLE Devices. In Figure 3.11, they present the current position.



(1)



(2)

Figure 3.11. Computing of current mobile node position

3.5.2 GEO Fencing

This step presents some places which are located near the current mobile position. Figure 3.12 shows a top view of the places and rooms on the map that the user can select as the chosen destination. The blue triangle is the current position, and the pink triangle is a target, for which the vertical view is illustrated in Figure 3.13.

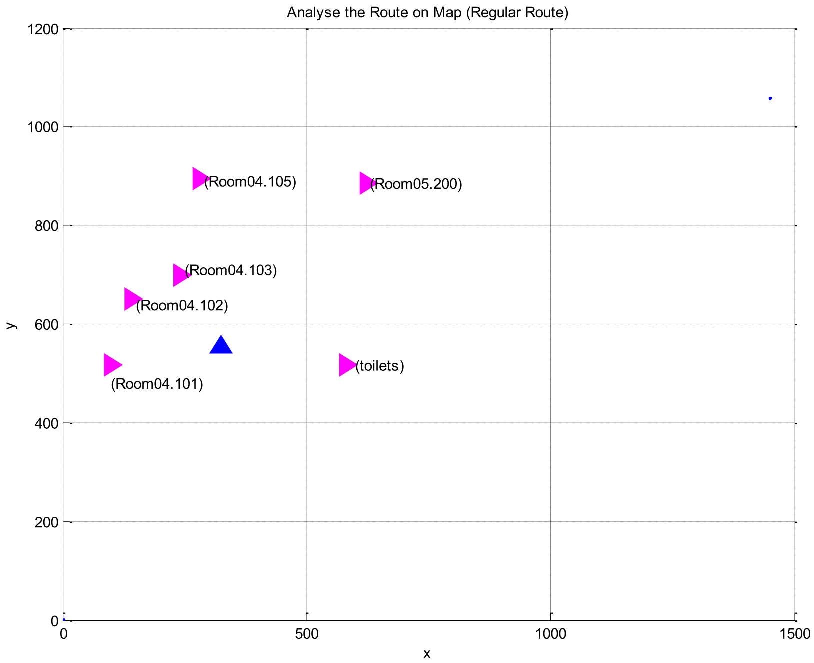


Figure 3.12. Top view of nearby places of the current mobile node position

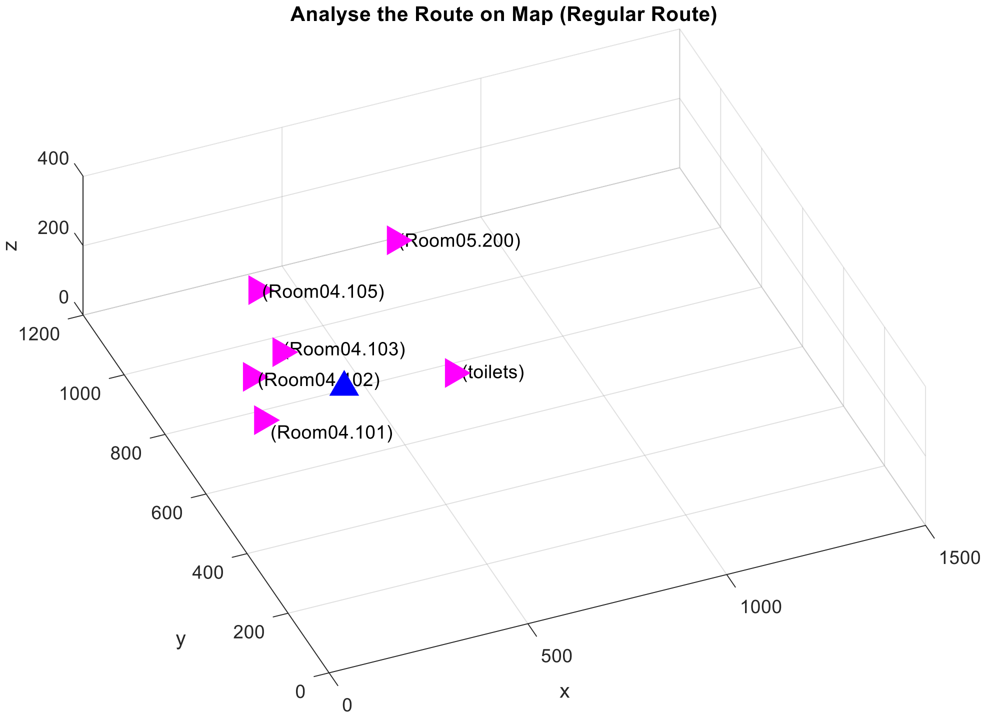


Figure 3.13. Vertical view of nearby places of the current mobile node position

3.5.3 Wayfinding

The indoor route can be created to follow the nodes. The problem is how to analyze to the precision of measurement of the current position.

- *Regular Route*

The user starts to walk from Level 4 to level 5 (room 11.05.200), and Figure 3.14 shows the start position passing six nodes to the target location as the top view. Figure 3.15 is the vertical view, which shows the indoor route including the same level and linked to a different level of the building.

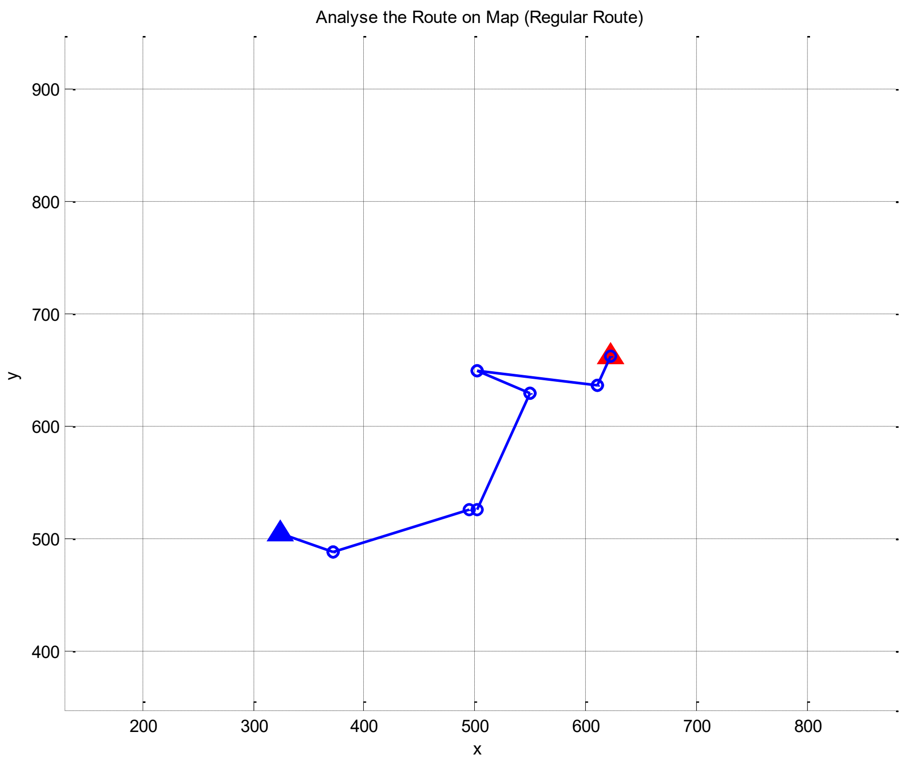


Figure 3.14. Way finding of regular route on the top view

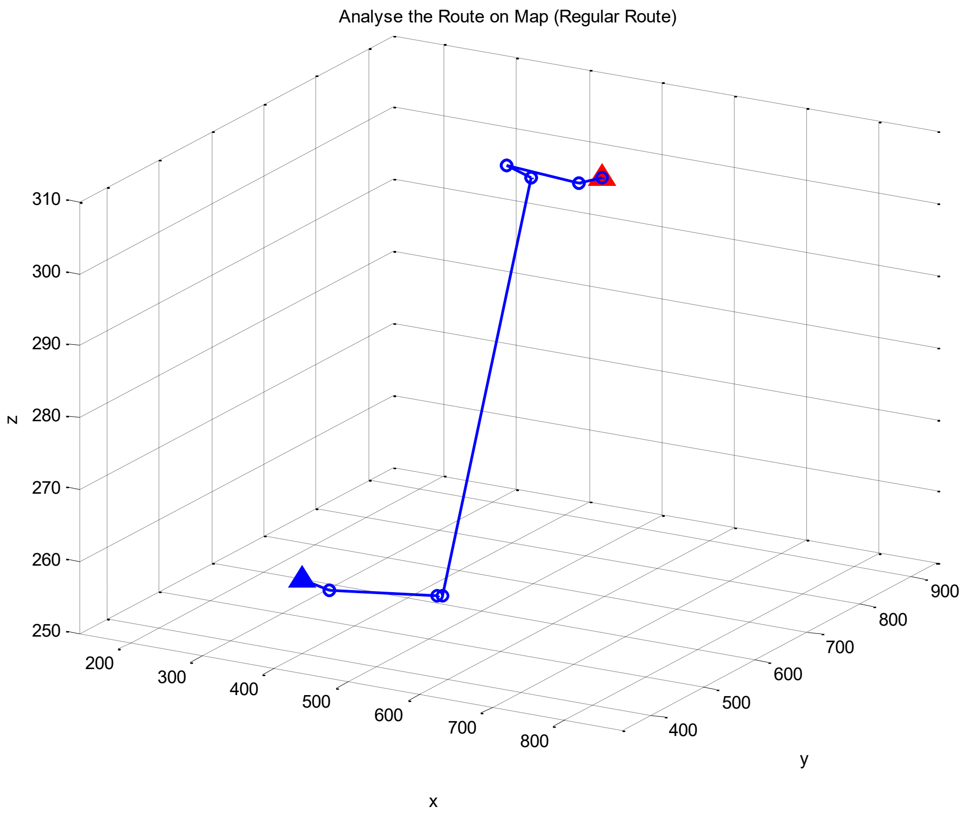


Figure 3.15. Way finding of regular route in the vertical view

- *Emergency Route*

When an emergency is occuring the route will change so navigation is from the original user position to the outside of the building and/or via a fire exit. If the user is staying on Level 4 , it will look for a fire exit door on Level 4 first. The figure below shows the route that starts from the current position and passes six nodes to the target location as shown in Figure 3.16 for the top view and Figure 3.17 for the vertical view which can show the route on a different level of the building.

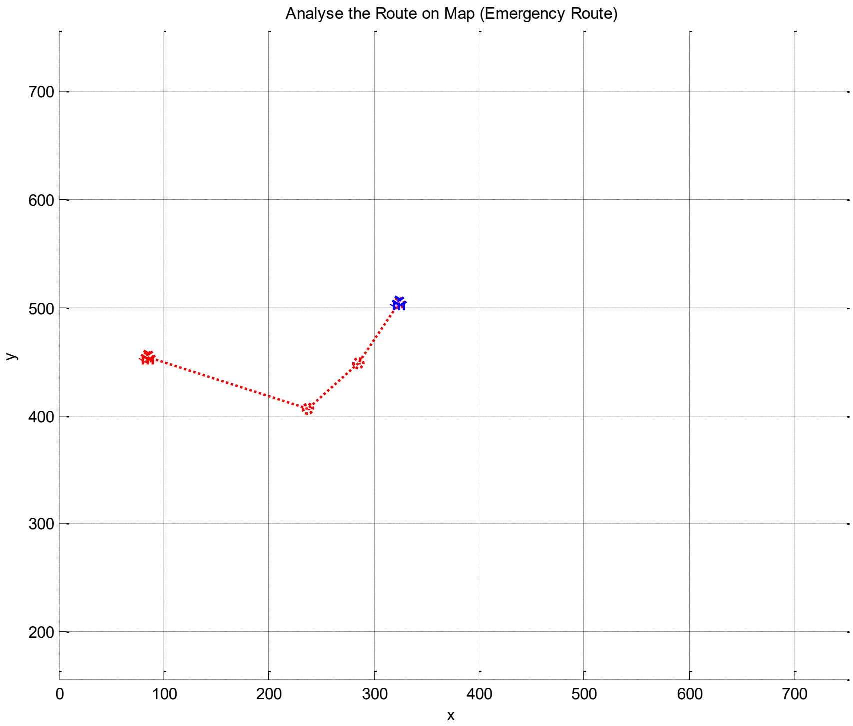


Figure 3.16. Way finding of emergency route on the top view

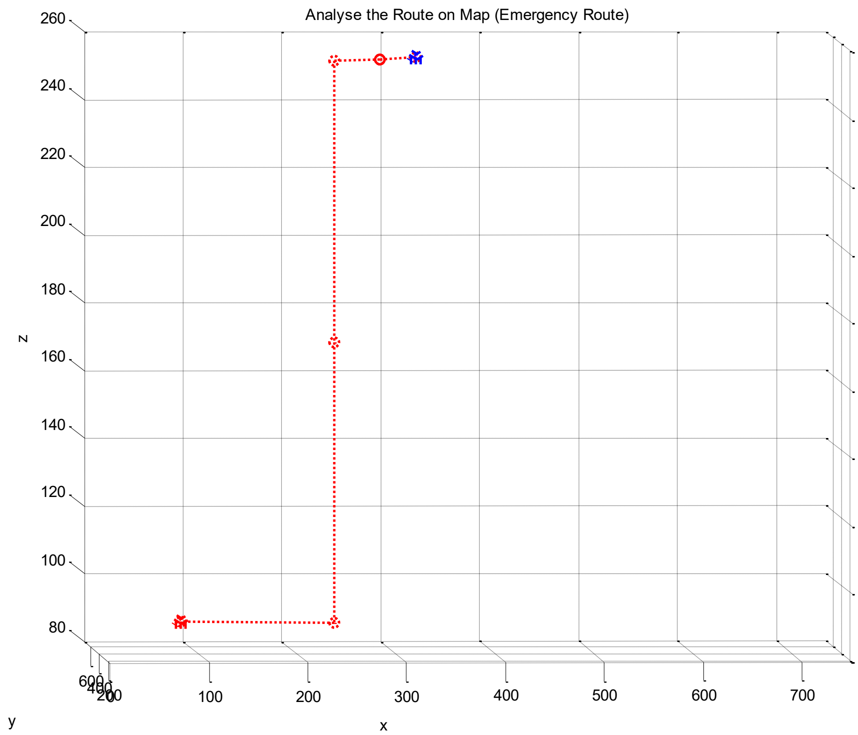


Figure 3.17. Way finding of emergency route on the vertical view

3.6 Summary

In this chapter, a Multi-Level Indoor Navigation Ontology is presented. It also provides the investigation of the indoor spaces from the perspective of navigation. It presents the construction of indoor navigation ontology and the algorithm is explained as to how the theory can be applied to indoor mobile applications. The ontology designs classes of nodes, links, building status and the route array. The ontology designs the nodes on a floor plan building map, and each level of the building can link to multi-level node techniques. The ontology describes the nodes for an indoor navigation search under both normal and emergency situations. The model is designed to provide indoor localization information, which is compatible with the combination of Bluetooth devices to determine the user's current position. This ontology model contributes to a new standard for indoor localization information for LBS indoor navigation. Indoor navigation is one of the functions for LBS with high assurance, one of its quality requirements. As well as working under normal situations, the LBS should still work in emergencies, such as fires, building power shut downs. The high-reliability LBS should be able to assist users to find the best exit route to the outside of a multiple level office building, shopping mall. under all circumstances with high reliability. The indoor navigation between the user and LBS has three steps in the navigation process flow for users, including Indoor Positioning, Geo-Fencing, and Way-finding.

Chapter 4
Development of Indoor Space Ontology for Finding Lost Property

This chapter is organized as follows. Section 1 will describe the introduction. Section 2 will propose the development of the analysis of finding property in an indoor space. Section 3 describes the type of nodes of the ontology. Section 4 presents the ontology architecture. Section 5 details the algorithm for finding the lost property using ontology.

4.1 Introduction

Mobile phones, wallets, handbags, and notebooks are valued personal property. They may be lost or moved to somewhere either outside or inside a building. Recently, some mobile applications can find the lost property outdoors using GPS technology such as using the "*Find my iPhone*" app on the iOS, where it can look for a lost iPhone, iPad, iPod touch, Apple Watch, and AirPods. 90% of people's activities are in the indoor environment (Li et al. 2016). In an indoor environment, finding lost property is more difficult because there is no standard device for looking for such items.

Usually, when someone loses an item inside a building, he/she will request the security of the building to help to look for the lost property. The property might already be found by others and deposited at the building lobby. Security may also use the CCTV monitoring system to search for the lost property. If a person is unable to remember his/her activities and movement in the building before the property was lost, they may spend more time searching for their valued property.

An indoor environment causes complexity in finding a route to the lost property due to closed corridors, multiple floors, electricity shut down, locked rooms, building maintenance, or the property being moved. All these situations are related to dynamic information. This thesis develops a dynamic indoor space model and technology to support the finding of lost property in an indoor environment. The various contexts are considered for indoor searching such as the context of search, location information, intent or words. The designing of the ontology is fundamental for conducting an indoor search as it can improve the efficiency of searching and provide the object's location with a higher accuracy. This research will present an indoor space ontology for finding lost property.

This chapter proposes a multi-level indoor navigation ontology for finding lost property in an indoor environment using a mobile phone. The main contribution of this study is a new ontology that can classify the static and dynamic location information in a multi-level indoor environment using the concept of nodes. Bluetooth Low Energy devices (BLE) set up on the walls of the building are used in our research for distance measurement. The mobile phone works as a receiver, using a specific application on the smartphone to obtain the position of the valued property and send it to update the ontology. A privacy policy is designed into this ontology.

4.2 Analysis of Finding Property in an Indoor Space

Finding lost property has three activities: analyze the current user's location, compute the property location, and find the route between the two. In these activities, there is a need to consider restrictive measurement of distance, multiple floors in the building and complex dynamic space information. Figure 4.1 demonstrates the lost property search using Bluetooth Low Energy (BLE) devices.

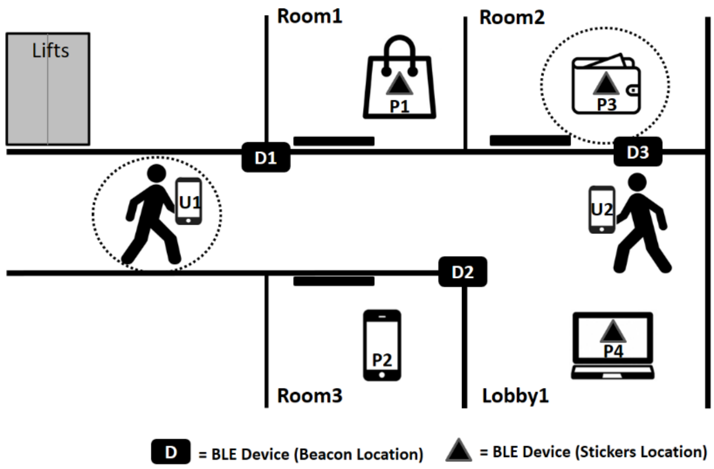


Figure 4.1. The lost property and BLE devices on map

This approach uses two types of BLE devices in searching for lost property: "*Beacon Location*" and "*Sticker Location*." These two types of locations are illustrated in Figure 4.1.

Firstly, this approach builds a beacon network inside a building. These beacons are installed statically in the corridors of the building and are used for calculating the distance between the beacons and the person who is searching for lost property and walking in the corridor. They are called "Beacon Location." They are setup on the walls in the building. In Figure 4.1, D1, D2 and D3 are Beacon Location devices.

Secondly, for computing the property location, this method uses a sticker type of BLE devices to stick on the valued property. These devices are movable with the property and can help to identify their locations inside the building. Considering the privacy policy involved in applying our approach, the permission must be sought for accessing these devices. The location of the sticker is called the "Sticker Location."

Lastly, this approach finds a route to determine the corridor for navigating from user's location to the destination of the property. Figure 4.2 shows the possible path to find a property inside the building.

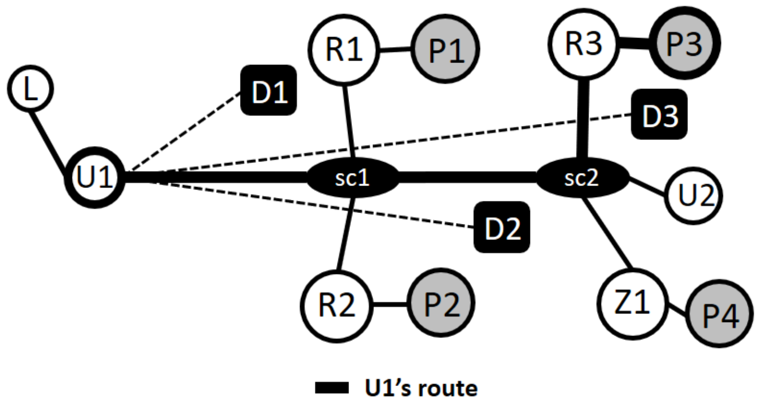


Figure 4.2. The route on the map present with all nodes

In Figure 4.3, nodes are displayed on the map. *D1, D2,* and *D3* are the BLE devices. *U1* and *U2* are two current user's mobile phones. Each user has a different permission to access the properties and has a different route to go to their property. *U1* runs using *U1's route,* and *U*2 works using *U2's route*. *R1, R2, R3* are the rooms or the places in the building. *Z1* is zone area such as lobby or relaxing zone with sofa etc. *P1-P4* are the properties. This method designs two ways to use the information of *P1-P4*: when inside a room and when outside a room. *SC1* and *SC2* are the space coordinates in the corridor, which connects the route along the corridor in the building.

If the properties *P1-P4* are inside the room, they are fixed using the nodes of room position and zone area, because these properties are unable to receive the beacon signals inside the rooms, or may produce weak signals when smartphones are outside the room. This approach uses the information of the latest date and time when it was connected with

BLE devices and users' devices, which might be *U1* or *U2*. They can lead to a link with the place. When the property is outside the room, it will link to the location nodes (*SC1, SC2*) on the corridor or the link nodes (*L*) which will connect to different floors such as the lifts or escalators.

Based on the analysis of the basic information needed to find an object, the design of the ontology is shown in the following section.

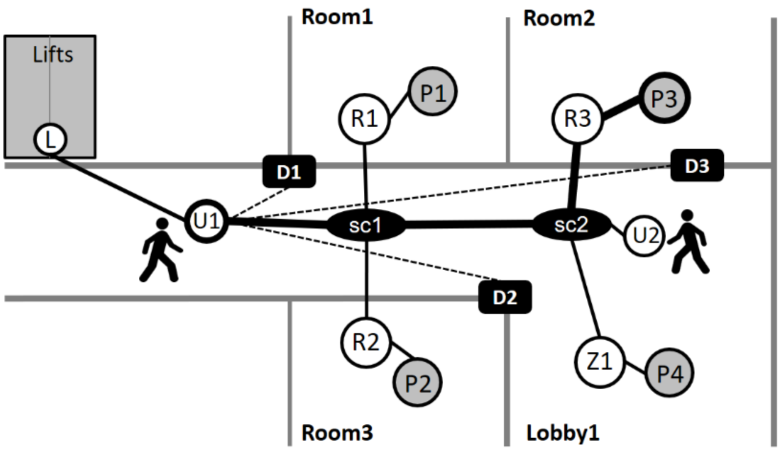


Figure 4.3. The route on map present with all nodes

In the example, *U1* is finding *P3* while *U2* may need support to update the recent position of *P3*. If there is not a smartphone near to this area, it will use the location of the last update by *U1*.

4.3 Type of Nodes

There is a need to design a new dynamic ontology for searching for lost property indoors. It will be adapted from previous research - the Multi-Level Indoor Navigation Ontology (Khruahong et al. 2017) - for creating dynamic information for moving objects including linking the zone area and different floors of a building together. Each user's smartphone will be adapted to be a receiver and send its location relative to a beacon's location back to the server for beacon networking. The application will use that information for analyzing the route.

The thesis develops an indoor property ontology that will utilize the information of space, property and route to find objects inside a building. This research utilises three kinds of nodes: static location node, dynamic node and static device nodes. All three kinds of nodes present the different objectives and can support the indoor navigation algorithm to being fast. Static location node is node of place locations which are fixed in position. Dynamic node is the node of the mobile which is always moving. Moreover, sStatic device node is the node of device location in the building, and it will be a fixed position to provide support to the position calculation inside the building.

4.3.1 Static location node

This type of node presents the information of places and the corridor space information and describes the destination space. The location information is applied to indicate the direction to the destination by using the node status. The nodes status includes place status, corridor status and escalator status. For example, escalator status could be 'On (The escalator is working regularly)', 'Off (The escalator is on maintenance status, not carrying passengers).'

4.3.2 Dynamic node

These nodes are divided into two types. One is the user's mobile phone or tablet's current position inside the building; users can update the position on ontology by themselves. The other, in addition to a user's mobile phone, is the dynamic node that includes other mobiles or some objects which have BLE devices in them. The recent position of valued objects are updated by other smartphones. These nodes will be adapted to be valued objects, such as a wallet, a handbag or a notebook which can move anywhere inside the building.

4.3.3 Static device node

This is the information of the BLE devices, such as positional coordinates, status, etc., which will collect information and calculate the current position of a user's mobile.

4.4 Ontology Architecture Design

The Indoor Space Ontology for Finding Lost Property is designed using a class diagram in Figure 4.4. These classes and attributes were designed to support the development of the finding of lost property inside the building. They can lead to finding the specific location of the properties.

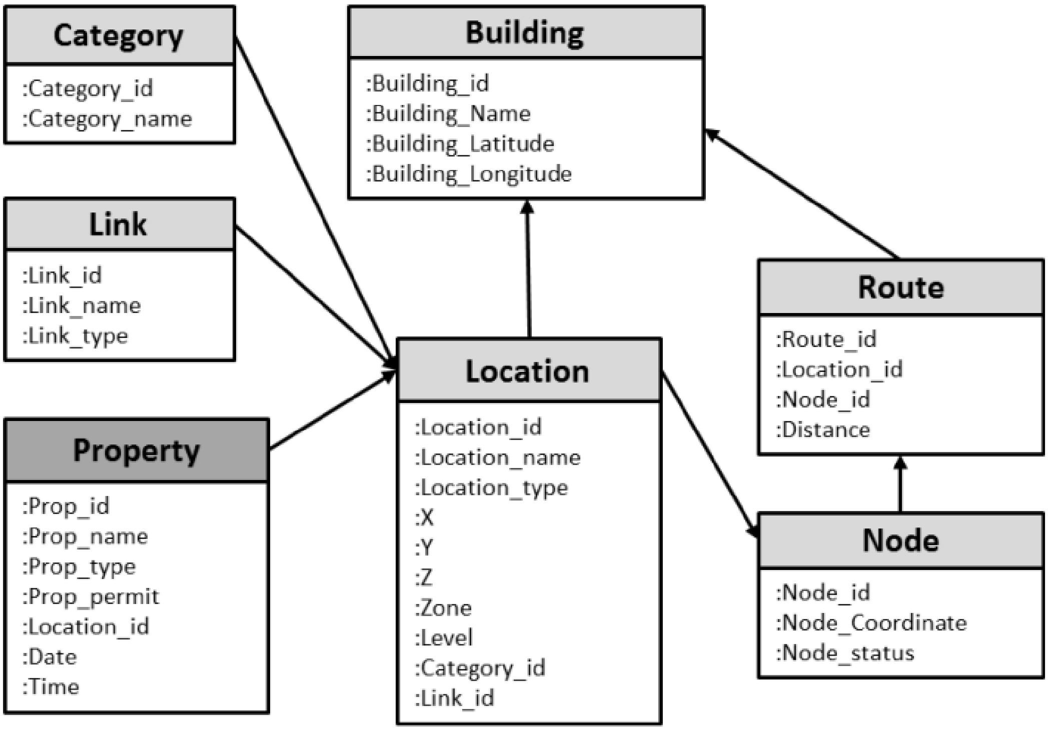


Figure 4.4. Indoor Space Ontology for Finding Property

This method extends the ontology used in previous research (Khruahong et al. 2017) by adding a *"*Property*"* class for the purpose of finding lost property. The primary classes are described as below.

Building: The activity of finding lost property in a building. The attributes of *"Building"* include *building ID, building name, the number of the floor of the building, building latitude* and *building longitude* (Khruahong et al. 2017).

Location: Location defines the physical coordinates and relative space relationship in a building.

Node: Node labels a place inside a building. Node has attributes of *Node ID, Node coordinate, Place name*, *Category* for user's searching service type criteria, *Zone* in the floor, *Level* in the building, and Node *Status* (Khruahong et al. 2017).

Category: Category classifies the places in a building. The groups of a category could be a classroom, lab, or meeting room.

Route: Route defines the pathway to find the lost properties.

Link: Link represents the connection from a node to a different floor of the building vertically (Khruahong et al. 2017).

The major attributes of the ontology are defined in Table 4.1.

Table 4.1 Terminologies for Some Attributes in Ontology

Terminology	***Definition and example***
ID	ID is a unique label for each node, use for calling the node shortname which each letter in the ID has a different meaning
Coordinate	(X, Y, Z) in Euclidean space
Place_name	Place name or all connection in the building (Classroom 203)
Level	The floor number of a building. (Level 8)
Zone	A zone is a connected area specified on a floor. (Zone08003)
Status	Node has status over time and situation (On-Off).

In finding property activity, a “Property” is described in detail as in Table 4.1. For this ontology, two rules have been designed to handle two major concerns.

Rule 1: The privacy policy. Some valued objects should not be accessed by someone who is not the owner or does not have permission. This rule gives permission to the administrator or owner to access the information of the lost objects in order to find them.

Rule 2: BLE device data collection time. The beacon signal may be blocked from the wall when the objects are placed in a room. The *Sticker Location* data will be collected using the latest date/time before they lost the connection to the location BLE devices. This design can estimate the last location of the lost property.

These rules are organised into “Property Class” as in Table 4.2.

Table 4.2 Attributes of Property Class in Ontology

Attributes	*Definition*	*Example*
Prop_id	A unique label for a property node	MB01_01,WL05_01
Prop_name	A unique label for a property name node	MackyWallet1,MobileiP1
Prop_type	Type of properties node	Wallet, Notebook
Prop_permit	Permission level for this device to consider privacy policy.	L51-Nd2_0001
Location_id	ID of a location node	L51-Nd2_0001
Date_Time	Date and time	2016-09-12:10.35am

4.5 Algorithm for Finding Lost Properties using Ontology

To apply this ontology, this thesis uses a flow of 4 steps for finding lost objects: (1) compute the user's current location, (2) determine the object location, (3) find the route to go to the object location and (4) update object position as shown in Figure 4.5.

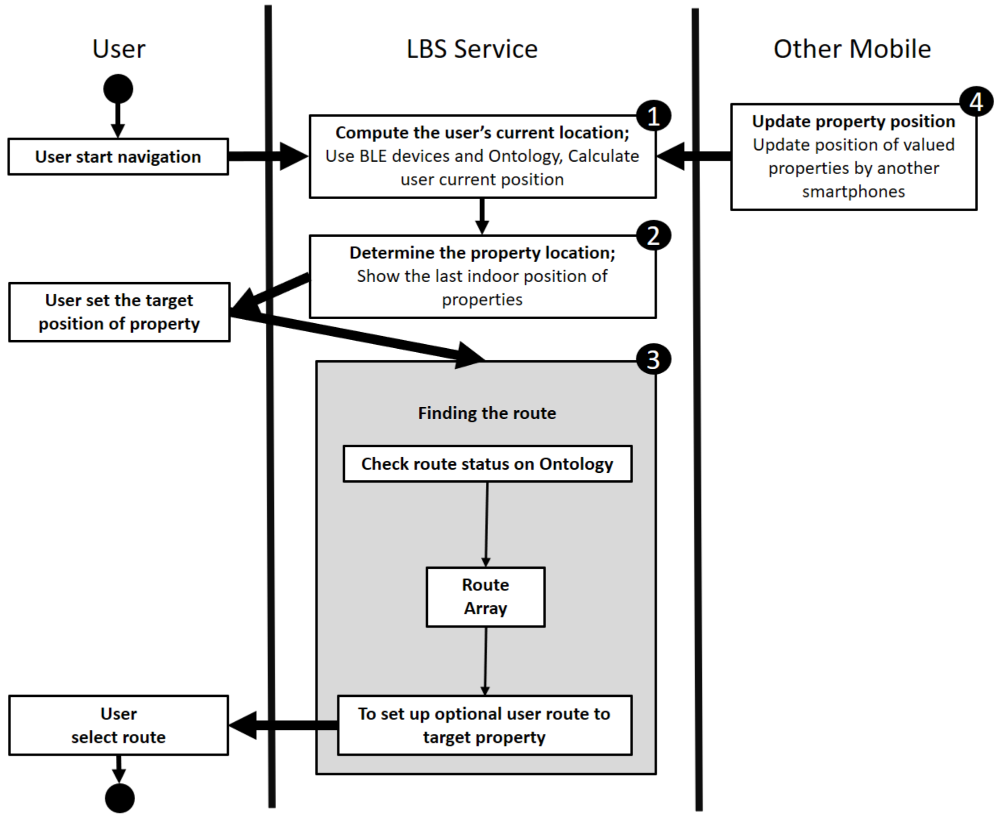


Figure 4.5. Diagram for using the Multi-Level Indoor Navigation Ontology for Finding the Lost Property

4.5.1 User's Current Location

This ontology approach will use at least three BLE devices to compute the current user location by using *Beacon Location* and the received signals from beacons. Beacon signals include Received Signal Strength Indicator (RSSI) signals, or direct distance data. Figure 4.6 illustrates this current user's location process.

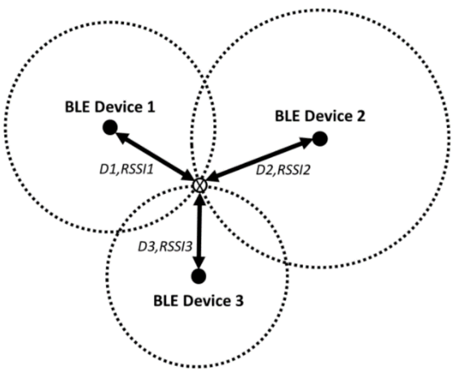


Figure 4.6. Three BLE devices to compute the current location

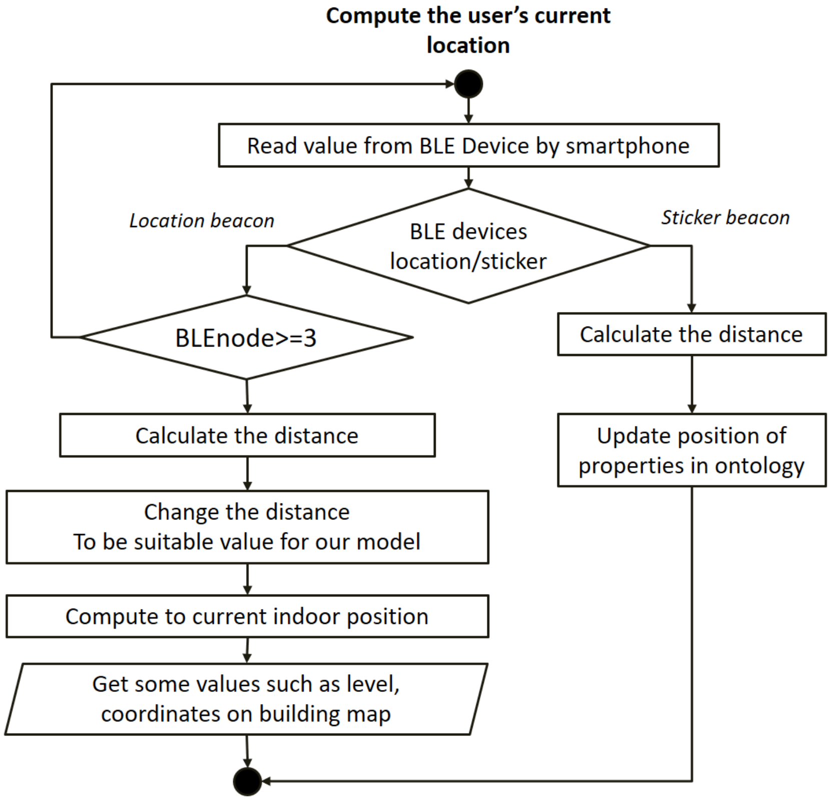


Figure 4.7. Compute the user's current position process

4.5.2 Determine the Object Location

BLE device *Property Sticker* is on the lost object. The last position and last time/date where the object is located or was last actively in use are determined from the ontology. If the signal of the *Property Sticker* is lost in the area, the Location ID nearby is set for the object. It can be a location of a room or in a corridor.

This thesis uses the same approach for computing user location to determine the location of objects. The close Location ID is set on the ontology where the lost object was last connected to the system. This position will be adapted to make the decision for finding lost objects.

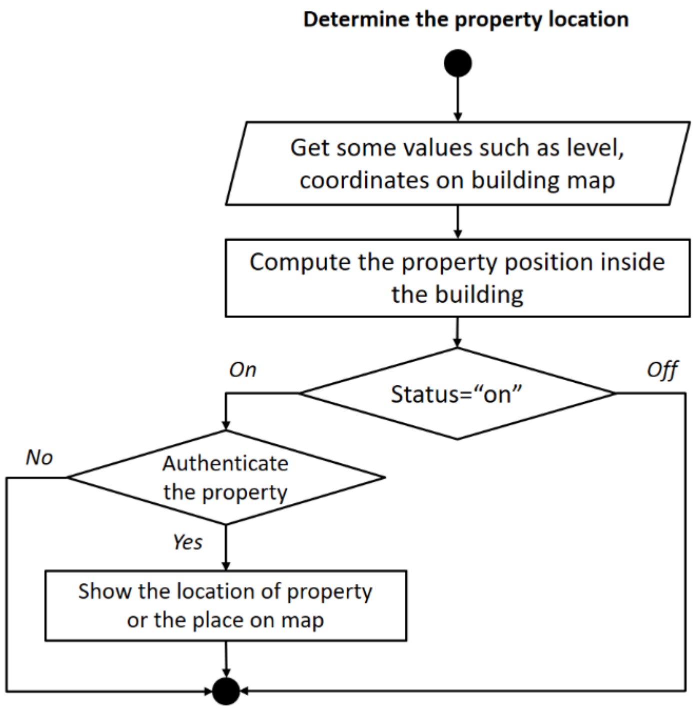


Figure 4.8. Determine the property location

4.5.3 Finding the route

Finding the route is determined from the user's current location and the object's location; the path will be drawn from user to the object, with an array of nodes on the map. Considering the privacy policy, the access permission level is set on the ontology at this step.

In this research 'Estimote iBeacons' are used for Beacon Nodes and 'Estimote Stickers' for 'Property Sticker' (Estimote 2017). The distance errors by using Estimote beacons are around 3 meters. This level of positioning accuracy is enough for finding a lost object.

4.5.4 Update object position

This technique needs to use another smartphone for updating the position of valued objects. They can assist to determine the recent position of those objects. While users would like to find some valued objects, they may not know the specific location of lost objects. Therefore, this thesis will show how to design the route and recommend the area where users should focus their search.

This research uses the multi-level indoor navigation ontology and adds the tracking property for updating the position of objects via another smartphone.

Update object position is a support to calculate the recent position of the lost property. The smartphone can read the signal of BLE devices on the object. The signal information will be sent to the LBS service for updating the ontology.

As this research will focus on privacy for the user, another smartphone without appropriate permissions cannot see other' s objects on their smartphone. Only building security staff can use this via the application. They will be permitted to use this application for helping someone who has asked for their help to find lost property in a building.

4.5 Summary

In this chapter, a Multi-Level Indoor Navigation Ontology for finding lost property is presented. It also provides the investigation of the indoor spaces from the perspective of navigation. Finally, the construction of indoor navigation ontology for finding lost property is presented. Validation of results and discussion will be presented in chapter 5. An indoor environment causes complexity in finding a route to lost property due to closed corridors, multiple floors, electricity shut downs, locked rooms, building maintenance, or the object being moved. All of these situations can be related to dynamic information. Therefore, this thesis develops a dynamic indoor space model and technology to support the finding of lost property in an indoor environment. The various contexts are analyzed for indoor searching such as the context of search, location information, intent or words. The designing of the ontology is fundamental for conducting an indoor search as it can improve the efficiency of searching and provide the object's location with a higher accuracy. The primary contribution of this study is a new ontology that can classify the static and dynamic location information in a multi-level indoor environment using the concept of nodes.

In the calculation of a mobile's position and an object's position, the WCL algorithm will be applied in the validation experiment in process for using the weight of value, instead of the mutual of the total. It can improve the precision to estimate position to be greater, which can be related to get the analysing of object position.

Chapter 5
Validation and Discussion

This chapter will present the validation of the developed ontology theories using experimental cases in a real multi-level indoor environment. The theories are detailed and the methods of calculating the results in chapters 3-4 are discussed. These will be split into two main theories for validation and experimentation in this chapter.

In the validation of the theories used in this thesis, test cases are set conditions for testing whether the feature can function as expected. The experiment has the test specifications; it defines requirements that will determine test *route_array* results. The *route_array* is the result of the set of route nodes which can be analyzed from the algorithm and can navigate to the chosen target. This section of the thesis shows the design of the test procedures for finding the experimental results.

The steps of the testing procedure are:

1) Draft a building map and set coordinates on it, with ontology
2) Plan the mark of the current position and the chosen destination
3) Determine and set the real route from initial position to the target position for comparison with the validation program
4) Collect data from a real area, in this case, Building 11 at UTS
5) Conduct validation using Matlab
6) Test of the *Route_array*
7) Comparison of the result (error distance, correction route, all distances)

The experiments are designed to validate the ontology structure and the ontology algorithms for the task ontology.

The tested items for the ontology structures are:

Table 5.1 Ontology experiment

Ontology	Tested ontology structure items	Tested task ontology items
Multi-level Indoor Navigation Ontology for LBS	Location class, Route array class, status class, link class, zone class	Finding the route for emergency and normal situations
Multi-level Indoor Navigation Ontology for finding lost property	Location class, Route array class, link class, zone class, Property class User mobile phone attribute class	Finding the route for looking for lost object's location

In the following sections the procedure is determined and explained, including the experimental setup, iBeacon Data, validation of the Multi-level Indoor Navigation Ontology, validation of the Multi-level Indoor Navigation Ontology for Finding Lost Property.

5.1 Experimental setup

The purpose of the experiment is to validate the multi-level indoor navigation ontology for two theories which are designed and detailed in chapters 3-4. These theories are applied to find a route using a smartphone and an iBeacon network in a multi-level building. The detail of the experiment setup is as follows.

5.1.1 Devices

BLE devices or iBeacons are installed on the walls in the building, 12 items on each floor. The distance between each iBeacon is around 15 meters. The iBeacons used are the commercial "*Estimote*" devices. They are used in two ways in this research, as Location or Proximity Beacons (Figure 5.1 a,b) and as Stickers (Figure 5.1 c). An iBeacon can also be implemented in an application for an indoor positioning system, allowing smartphones to determine their approximate location or context. Proximity is about using an app to identify their proximity or closeness to an area of interest. First, the area is tagged with

Proximity Beacons (Location Beacons). Once this is done, Bluetooth-enabled devices such as iOS and Android smartphones can discover if they are in the proximity of objects which are identified by Estimote Stickers - tiny beacons stuck to objects as shown in Figure 5.1 (c).

(a) Estimote Location Beacons

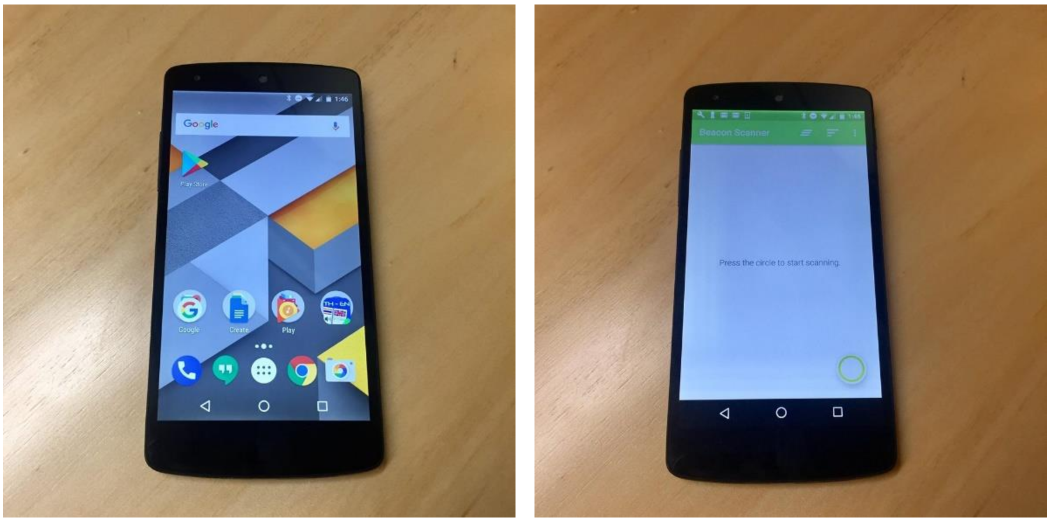
(b) Estimote Proximity Beacon

(c) Estimote Stickers for sticking on objects

Figure 5.1. All iBeacon devices for the experiment

Indoor Location is the technology of replacing GPS for indoor navigation, where there is no reliable satellite coverage. Setting up a group of Location Beacons or iBeacons throughout a space will allow the automatic mapping of an area and the production of a floor plan. An iOS or Android smartphone app provides the indoor (x,y) coordinates of the device.

Smartphone, this research used LG Nexus 5 as shown in Figure 5.2. It has the Bluetooth capacity which allows it to be adapted for the experiments in this research.



(a) (b)

Figure 5.2. The mobile phone used for data collection "LG Nexus 5"

5.1.2 Mobile application for data collection

In the experiment for this research, an Android application is used for collecting data. It can scan every iBeacon device (UID, URL, TLM frames and etc.) in its vicinity.

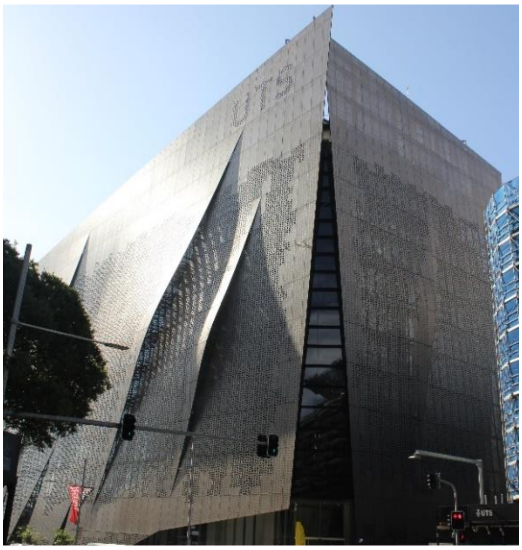
The app collects data from beacon data including:

- UUID, Minor and Major values for iBeacons/Altbeacons.
- URL, UID and TLM frames for Eddystone.
- Proximity value (immediate, near, far)
- Distance to beacon
- TX and RSSI values
- The application can dump beacon data to local CSV file
- The application can send beacon data to a web API via POST requests
- Copy and paste single beacon data snippets

This application requires Bluetooth Low Energy (aka Bluetooth 4.0) integrated into the smartphone which runs at least Android 4.3. It can be downloaded from the Google Play Store (Ref: https://play.google.com/store/apps/details?id=de.flurp.beaconscanner.app)

5.1.3 Experiment Location

The location used for experiments in this research is Building 11 of the University of Technology Sydney (UTS), Australia which is located between Wattle and Jones Streets on Broadway, Ultimo. This building has 12 floors and 4 basement levels. The Faculty of Engineering and Information Technology building has lecture theatres, class rooms, computer laboratories, study spaces and offices.



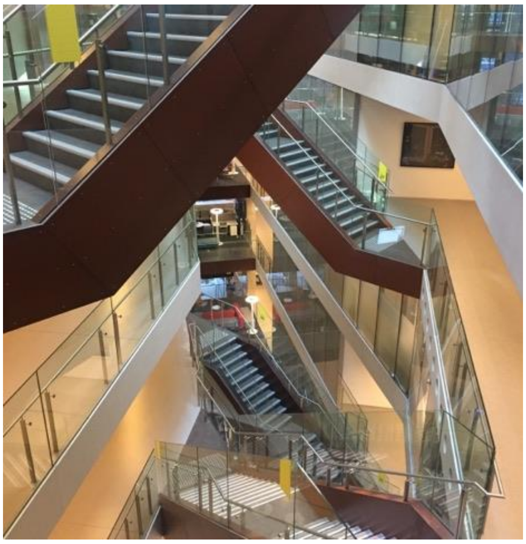
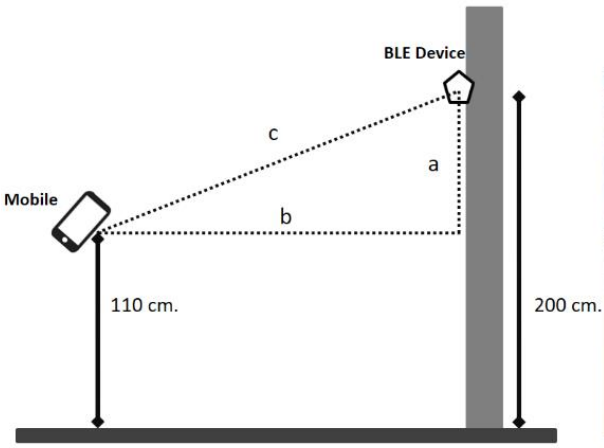


Figure 5.3. Building 11, Faculty of Engineering and Information Technology, UTS

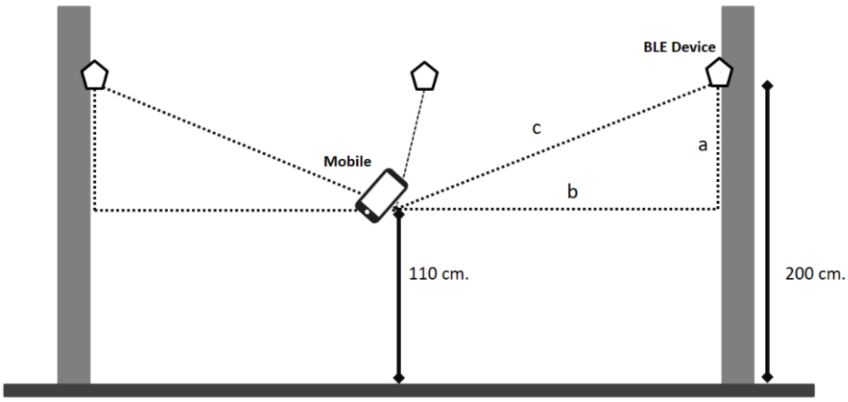
5.1.4 Data collection setup

The smartphone set up for getting the data on each floor is shown in Figure 5.4. The height of the smartphone on the tripod is 110 centimeters from the floor. Although the *c-side* of the triangle is the value obtained by the smartphone, this thesis uses the *b-side* for calculation of distance with the algorithm.



(a) (b)

Figure 5.4 Using the tripod for data collection



(a)

(b) (c)

Figure 5.5. Attaching iBeacons on the walls inside the building

5.2 iBeacon data

The iBeacon device has differences from other location-based technologies as the transmitting device (beacon) is only a one-way transmitter to the receiving smartphone, which requires the installation of a particular app in order to interact with the beacons. This method ensures that only the established application can follow users, potentially against their will, as they walk near the transmitters. For this research, the mobile application can get data from iBeacon devices. The set of data used for the experiment is collected by the mobile application within the building and is exported to a CSV file. This data is used to validate the finding of the route for indoor navigation.

For example:

UUID: 6541e376-cfcf-5602-dd06-7e5fd13759cd

Major ID: 38608

Minor ID: 1002

TX: -66

RSSI: -73

This data was collected by the mobile application. It was collected over six minutes at the same coordinate and is real data from Level 4 in Building 11, UTS.

1	Timestamp;TimeFormatted;UUID/Namespace;Major/Instance;Minor;TX;RSSI;Distance
2	1504503437630;2017-09-04 15:37:17;6541e376-cfcf-5602-dd06-7e5fd13759cd;38608;1002;-66;-73;1.3978662731868523
3	1504503437630;2017-09-04 15:37:17;c3783564-caf9-3571-5c1b-1c962f35d0bc;38608;1003;-66;-76;1.6213669524782652
4	1504503438754;2017-09-04 15:37:18;c3783564-caf9-3571-5c1b-1c962f35d0bc;38608;1003;-66;-77;1.671646413758628 7
5	1504503438754;2017-09-04 15:37:18;6541e376-cfcf-5602-dd06-7e5fd13759cd;38608;1002;-66;-76;1.7782905478357034
6	1504503439881;2017-09-04 15:37:19;6541e376-cfcf-5602-dd06-7e5fd13759cd;38608;1002;-66;-79;1.8736785099226096
7	1504503439881;2017-09-04 15:37:19;c3783564-caf9-3571-5c1b-1c962f35d0bc;38608;1003;-66;-78;1.7062766454939924
8	1504503441006;2017-09-04 15:37:21;c3783564-caf9-3571-5c1b-1c962f35d0bc;38608;1003;-66;-78;1.7418180712770754
9	1504503441006;2017-09-04 15:37:21;6541e376-cfcf-5602-dd06-7e5fd13759cd;38608;1002;-66;-79;1.9135710388068468
10	1504503442138;2017-09-04 15:37:22;6541e376-cfcf-5602-dd06-7e5fd13759cd;38608;1002;-66;-79;1.939022861124338

Figure 5.7. Collected data

5.3 Validation of the Multi-level Indoor Navigation Ontology for Location-based Service

5.3.1 Experiment design

The purpose of the experiment is to validate the multi-level indoor navigation ontology for location-based services, using smartphones to find the route in an iBeacon network in a multi-level building.

1) Background

The UTS Building 11 is the experimental location. This area has a complicated layout because it has many floors and many rooms. Several elevators, escalators and stairs link the different levels. This testing is designed and planned to get experimental results for this complex arrangement. This testing intends to test both a regular route and an emergency route. Nodes were created on the map such as coordinates (C), places (P), BLE devices (D), fire exit (E) or link (L) as shown in Figure 5.8. However, these nodes will be changed to specific node names for the experiments.

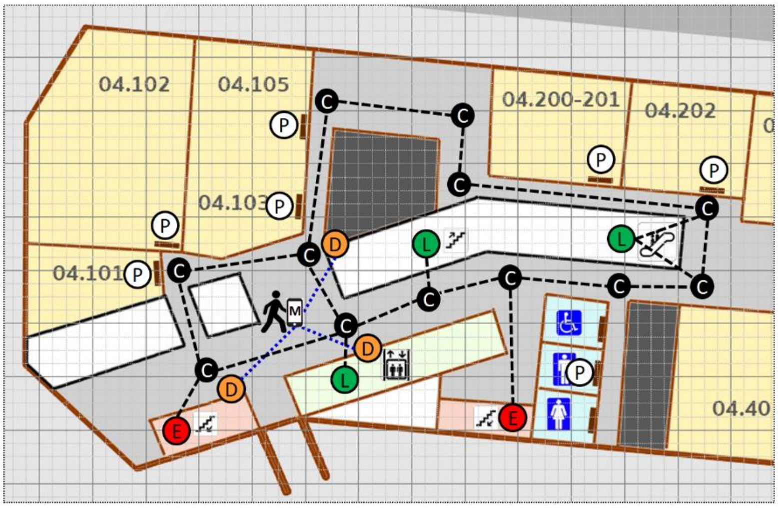


Figure 5.8 Example of nodes on the map

Following completion of the design, the Multi-level Indoor Navigation Ontology is applied to indoor navigation inside the building using the data from the BLE devices.

2) Objectives

The test plan for the Multi-level Indoor Navigation Ontology shall support the following objectives:

- Identify nodes and features in the indoor navigation model that are required to be tested
- Describe the approach to testing the theory
- Development of a test approach
- Design the test case
- Specify Pass/Fail criteria

It is necessary for the objectives listed above to ensure the successful development of the stage of acceptance experiment.

3) Scope

This testing is designed to find a preferred route for two situations; normal state and emergency state. These conditions follow the design in chapter 3. The Multi-level Indoor Navigation Ontology for Location-based Service is developed for multi-linking between the floors inside the building. Importantly, it can work in two situations; also this scope is planned and designed for testing and route validation for the user, including go to the same floor, go to a lower level, and go to a higher level.

4) Functional Requirements

From the situation inside the building, the experiment is designed with three functional requirements for the ontology validations, which are:

Requirement 1: REQ_FR_inBLD01

The first code for testing is"*REQ_FR_inBLD01*"*, which* means *Requirement of Finding Route in the Building in case 1*. This route shows how a user can travel on the same level of the building. In this case, the indoor navigation test is on only Level 4. Person A will be able to find a route on Level 4 . This person is set as the "user current position" on Level 4 in Building 11. The target room is Room.11.04.202.

Requirement 2: REQ_ FR_inBLD02

The second code for testing is *"REQ_FR_inBLD02",* which means *Requirement of Finding Route in the Building in case 2*. This route shows the user a way to travel to a different level of the building, in this case a lower level from level 5 to Level 4 . Person B will be able to find the route on Level 5 to Level 4. This person is set as the "user current position" on Level 5 in Building 11. The target room is Room 11.04.401 in Level 4.

Requirement 3: REQ_ FR_inBLD03

The third code for testing is *"REQ_FR_inBLD03",* which means *Requirement of Finding Route in the Building in case 3*. This route shows the user how to travel to a different level of the building, in this case a higher level from Level 4 to Level 6. Person C will be able to find a route on Level 4 to Level 6. This person is set as the "user current position" on Level 4 in Building 11. The target room is Room.11.06.103 on Level 6.

5) Test Case Design

The test cases in these experiments are as shown in the following table. The design is of a Multi-level Indoor Navigation Ontology for Location-based Service, detailed in Table 5.2.

Test Case 1: FR_inBLD01

FR_inBLD01- find the route to target room on same level

Test Case 2: FR_inBLD02

FR_inBLD02- find the route to target room from a higher level to a lower level

Test Case 3: FR_inBLD03

FR_inBLD03- find the route to the target room from a lower level to a higher level

Table 5.2. Three Test Cases in two states

Requirement #	Test case #	State1 #	State2 #
1-REQ_FR_inBLD01	FR_inBLD01- find the route to target room on the same level	Normal	Emergency
2- REQ_FR_inBLD02	FR_inBLD02- find the route to target room from the upper level to the lower level	Normal	Emergency
3- REQ_FR_inBLD03	FR_inBLD03- find the route to target room from the lower level to the upper level	Normal	Emergency

6) Test environment

- The hardware needed for this experiment is as follows:

- *BLE devices* or iBeacons installed on the walls of the building, covering each floor with distances between each iBeacon around 15 meters.

- *Smartphone,* using a mobile application for data collection; this research uses an LG Nexus 5. While collecting data the smartphone is mounted on a tripod.

- The software needed in this experiment is:

- An *Android application* called "iBeacon & Eddystone Scanner app." It will be used to collect the signal information include UUID, Major ID, Minor ID, RSSI, and Power TX.

- *Matlab R2016b*, this software will be applied to validate the route for Multi-level Indoor Navigation of Ontology for Location-based Service.

- The locations needed in this experiment are:

  The location used in this research is Building 11 of UTS. This building has 12 floors and 4 basements. It houses the Faculty of Engineering and Information Technology. The value of level on the map present the level of building in *z-value*, and the experiments used levels 2 to 7 such as Level 2=89, Level 3=172, Level 4 =255, Level 5=338, Level 6=421, and Level 7=504. They are the values for presentation on 3D building view on Matlab .

5.3.2 Experimental results

Experiment result will only get 'Pass' and 'Fail' if the route can correctly set the route from the starting point to the target point as the expected result. This is considered "Pass". However, the route result which does not follow the expected result, it will get "Fail".

Test Case 1: FR_inBLD01 (Finding Route in Building 01)

Person *A* will be able to find a route to the room on Level 4. This person is set as the "user current position" on Level 4 in Building 11. The target room is also on Level 4 (Room.11.04.202). The route is shown in Figure 5.9. The thick black line is the regular or normal non-emergency route and the thick red line shows the emergency route. The expected regular route includes MN, SC04017, SC04016, SC04015, SC04014, SC04013, SC04006, and Room04202 as shown on Figure 5.10.

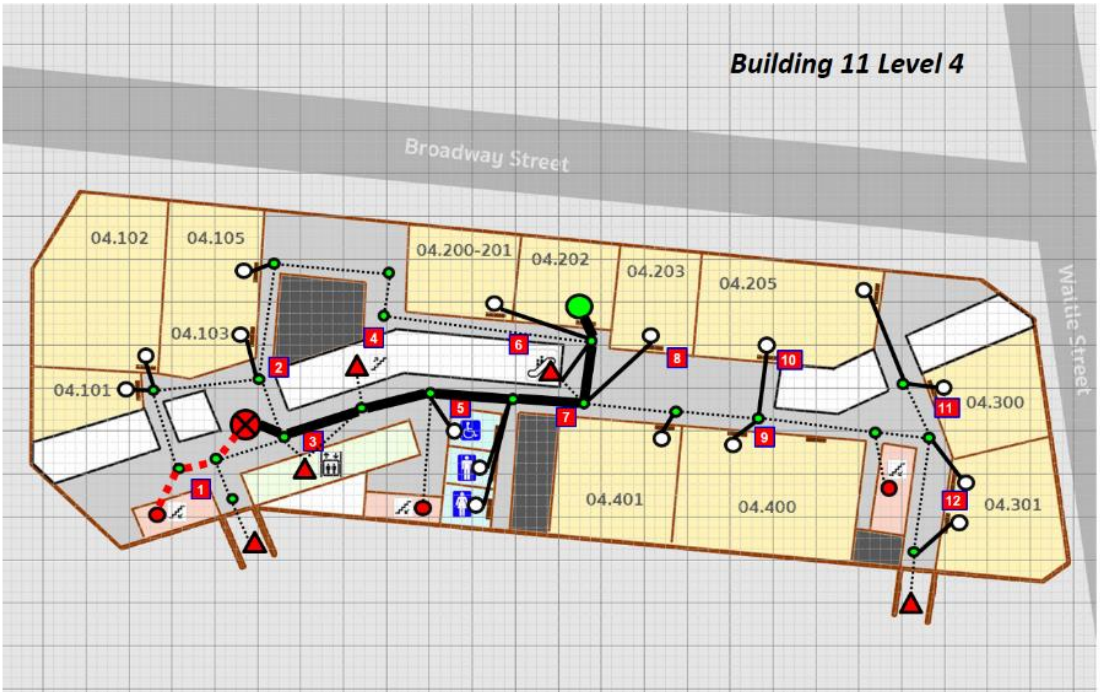


Figure 5.9. The route to Room 11.04.202 on Level 4 (Case 1)

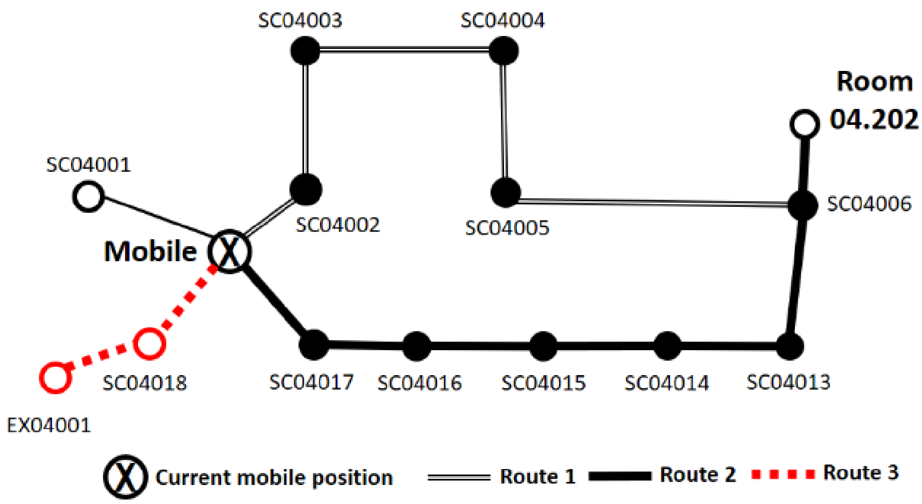


Figure 5.10. The node name of route to Room 11.04.202 on Level 4 (Case 1)

Figure 5.10 illustrates the node route in both states. The regular situation will include two routes (Route1, Route2), but the expected direction of this case is Route 2, selected because it is the best route and navigates the user to the destination (Room 04.202). In the emergency state, the Route3 will be selected for navigation and will allow the user to exit the building.

The results of this test case 1 is in Table 5.3. It shows both the normal and emergency route. This table details the result of the experiment in test case 1.

Table 5.3. Test Results for Test Case 1

	Test case 1: FR_inBLD01 **Normal state**	**Test case 1: FR_inBLD01** **Emergency state**
Route description	From Starting point to normal room door in the same level – Level 4	From Starting point to emergency door in the same level – Level 4
Building State	Normal	Emergency
Start point	***MN(324,555,255), sofa at front of lifts, Level 4***	***MN(324,555,255), sofa at front of lifts, Level 4***
Target point	***Room 04.202*** ***Level 4***	***Emergency door Level 4 (1)***
Test Flow	Figure 5.9	Figure 5.9
[Expected result] **Passing nodes**	MN,SC04017, SC04016, SC04015, SC04014, SC04013, SC04006, Room04202	MN, SC04018, EX04001
[Expected result] **True route array**	[MN,SC04017, SC04016, SC04015, SC04014, SC04013, SC04006, Room04202]	[MN, SC04018, EX04001]
[Experiment Result] - Computed passing nodes	MN, SC04017, SC04016, SC04015, SC04014, SC04013, SC04006, Room04202 Figure 5.10 (Route 2)	MN, SC04018, EX04001 Figure 5.10 (Route 3)

[Experiment Result] - Computed route array	[MN, SC04017, SC04016, SC04015, SC04014, SC04013, SC04006, Room04202] Figure 5.11	[MN, SC04018, EX04001] Figure 5.12
Result - Pass or Fail	Pass	Pass

The result of Test Case 1 is illustrated in Figure 5.11. User *A* starts from (324,504,255), where the target room is Room04202 (771,642,255) as shown in the 2-D map. The blue curve shows the user route to find the room. The plots shows that the route is correct; the final accuracy to the target coordinates is 2 meters.

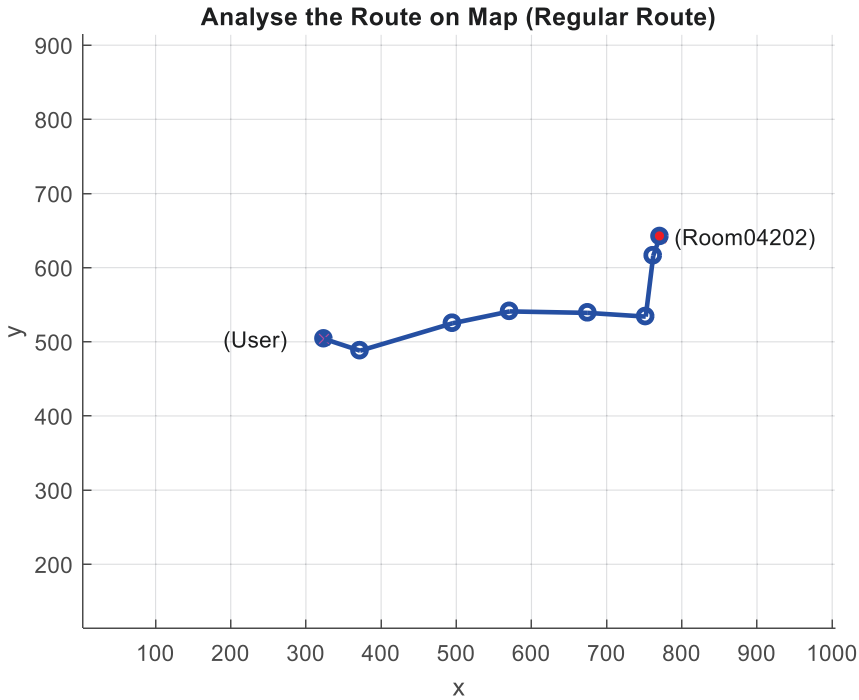


Figure 5.11. The normal route to Room 11.04.202 on Level 4 (Case 1)

Figure 5.12 illustrates the result for an emergency route in Test Case 1. When the building is in an emergency state, the route is to FireExit04001, which is fire exit door on Level 4 .

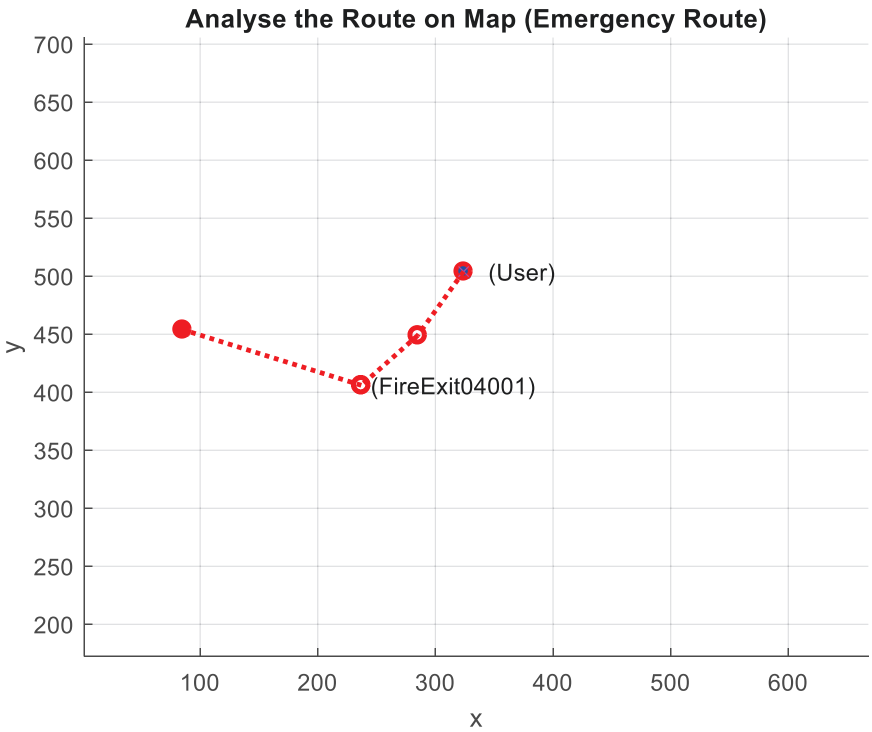
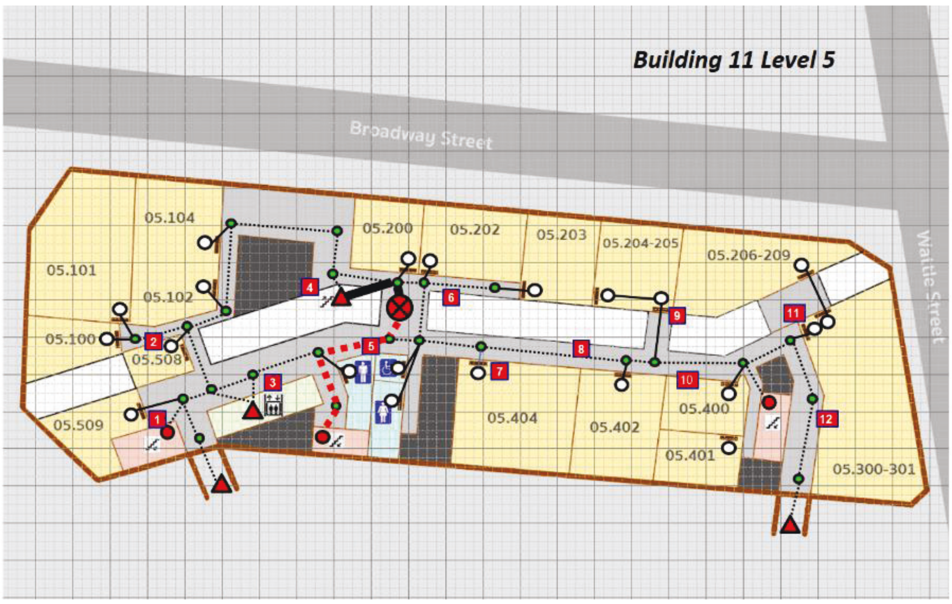


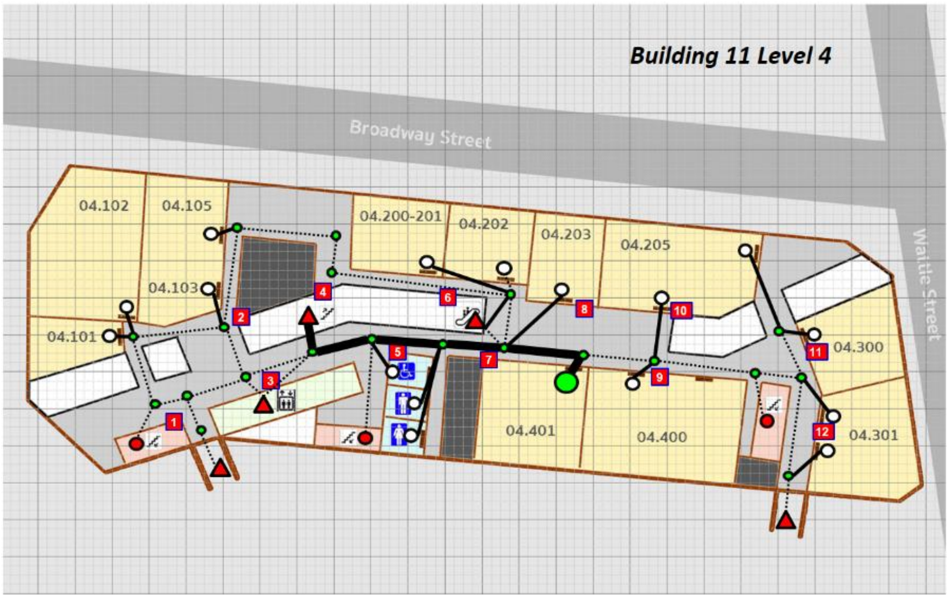
Figure 5.12. The emergency route to Room 11.04.202 on Level 4 (Case 1)

Test Case 2: FR_inBLD02 (Finding Route in Building 02)

Person B will be able to find the route from level 5 to a room on Level 4 . This person is at the "user current position" on Level 5 in Building 11. The target room is Level 4 (Room.11.04.401). The route is shown on Figure 5.13. The expected route includes MN, SC05007, LK05002, SC04016, SC04015, SC04014, SC04013, SC04012, and Room04401.

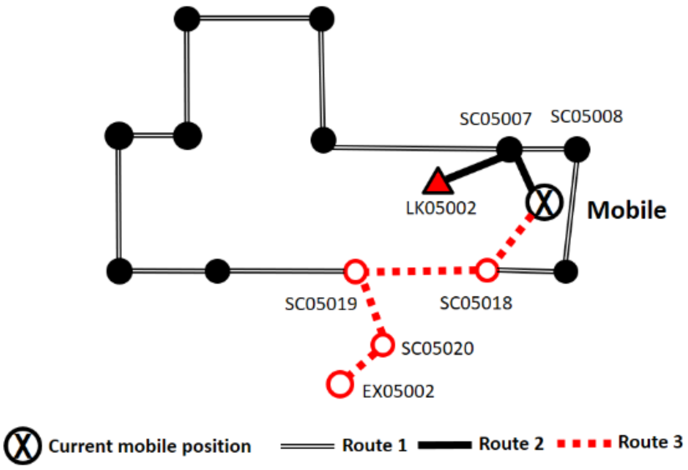


(a) Shows the map of Level 5 and the route link to Level 4 (includes emergency route)

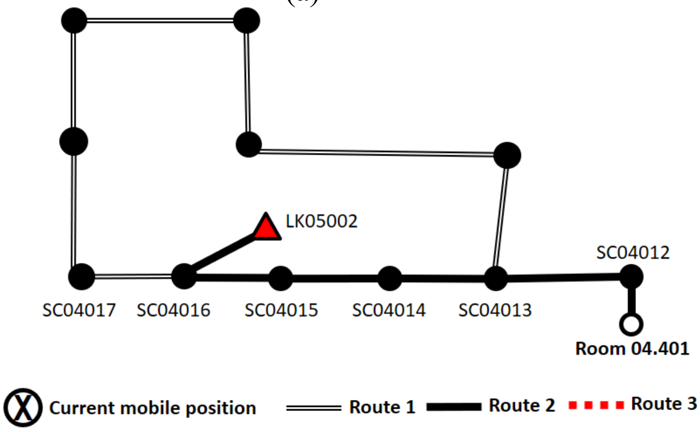


(b) Shows the map of Level 4 and the route link from Level 5

Figure 5.13. The route from level 5 to Room 11.04.401 on Level 4 (Case 2)



(a)



(b)

Figure 5.14. The route node from Level 5 to Room 11.04.401 on Level 4 (Case 2)

Figures 5.13 and 5.14 illustrates the node route for both states. The regular situation includes two routes (Route1 and Route2). In this case Route 2 will be selected because it is the best route to navigate the user to the chosen destination (Room 04.401). In the emergency state then Route3 will be selected for navigation, bringing the user to the building exit.

The results of Test case 2 are in Table 5.4. They show both the normal route and the emergency route. This table details the results of the experiment in test case 2.

Table 5.4. Test Results for Test Case 2

	Test Case 2: FR_inBLD02 **Normal state**	**Test Case 2 : FR_inBLD02** **Emergency state**
Route description	From Starting point to normal room door from Level 5 to Level 4	From Starting point to emergency door from Level 5 to Level 4
Building State	Normal	Emergency
Start point	***MN(612,445,338), front of toilets, Level 5***	***MN(612,445,338), front of toilets, Level 5***
Target point	***Room 04.401*** ***Level 4***	***Emergency door Level 5 (2)***
Test Flow	Figure 5.13	Figure 5.13
[Expected result] **Passing nodes**	MN, SC05007, LK05002, SC04016, SC04015, SC04014, SC04013, SC04012, Room04401	MN, SC05018, SC05019, SC05020, EX05002
[Expected result] **True route array**	[MN, SC05007, LK05002, SC04016, SC04015,	[MN, SC05018, SC05019, SC05020, EX05002]

	SC04014, SC04013, SC04012, Room04401]	
[Experiment Result] -Computed passing nodes	MN, SC05007, LK05002, SC04016, SC04015, SC04014, SC04013, SC04012, Room04401 Figure 5.14	MN, SC05018, SC05019, SC05020, EX05002 Figure 5.14
[Experiment Result] -Computed route array	[MN, SC05007, LK05002, SC04016, SC04015, SC04014, SC04013, SC04012, Room04401] Figure 5.15, 5.16	[MN, SC05018, SC05019, SC05020, EX05002] Figure 5.17
Result - Pass or Fail	Pass	Pass

The results for Test Case 2 are illustrated in Figure 5.15. User *B* starts from (614,608,338) on Level 5, the target room is Room04401 (871,484,255) in the 2-D map. The blue curve shows the user route to the room. The green line links from the 5th floor to the 4th floor (LK05002). The plots show that the route is correct; the final accuracy to the target coordinates is 2 meters.

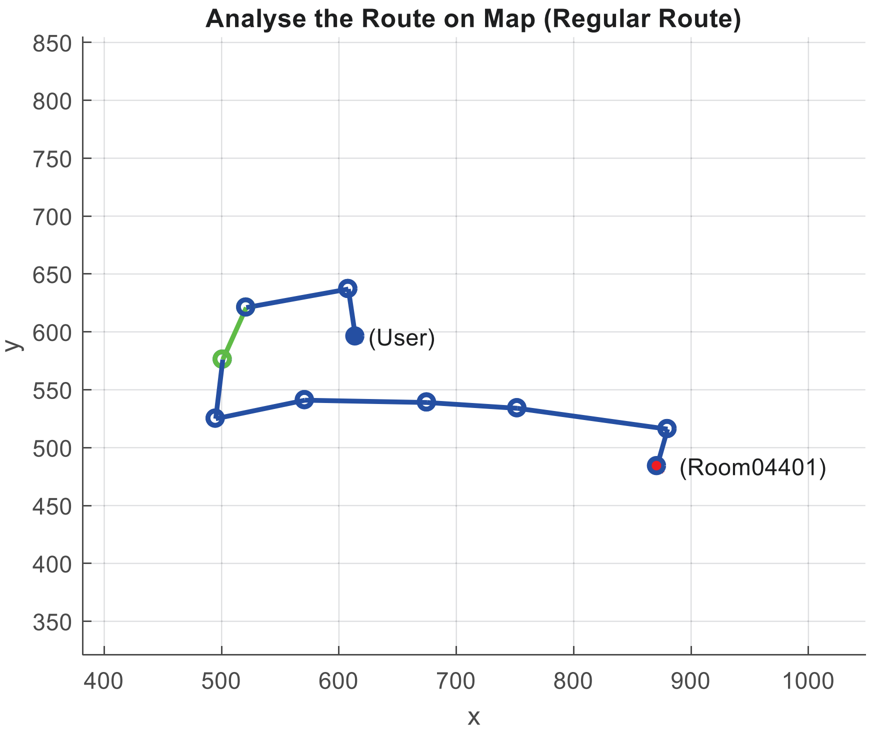


Figure 5.15. The normal route from level 5 to Room 11.04.401 on Level 4 (Case 2)

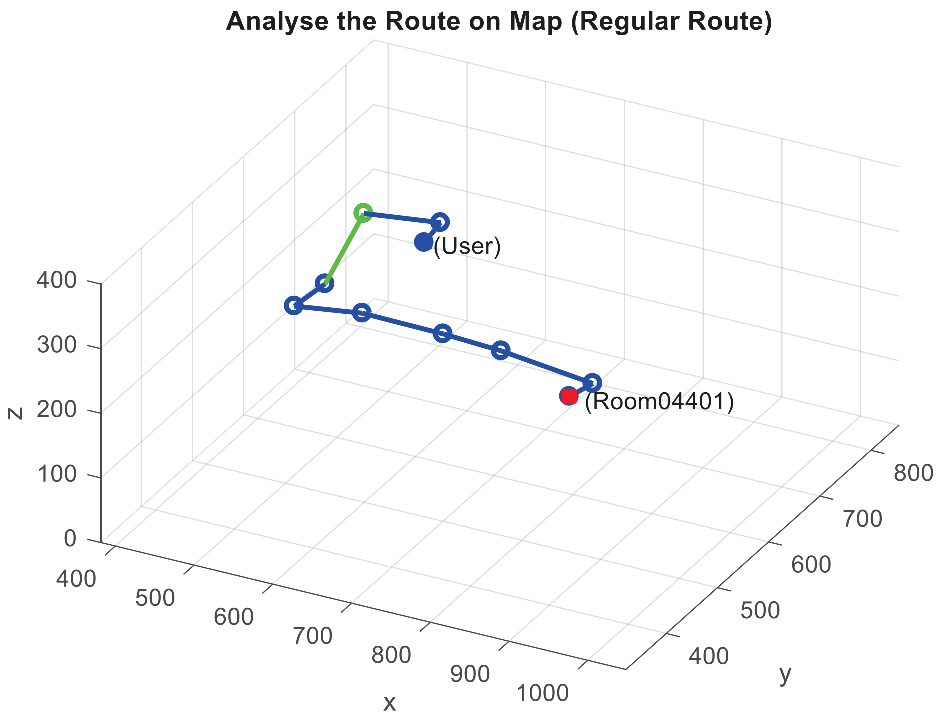


Figure 5.16. The normal route from Level 5 to Room 11.04.401 on Level 4 (Case 2) vertical view

Figure 5.17 illustrates the result for the emergency route in Test Case 2. When the building has an emergency state, the emergency route navigates to FireExit05002 on Level 5.

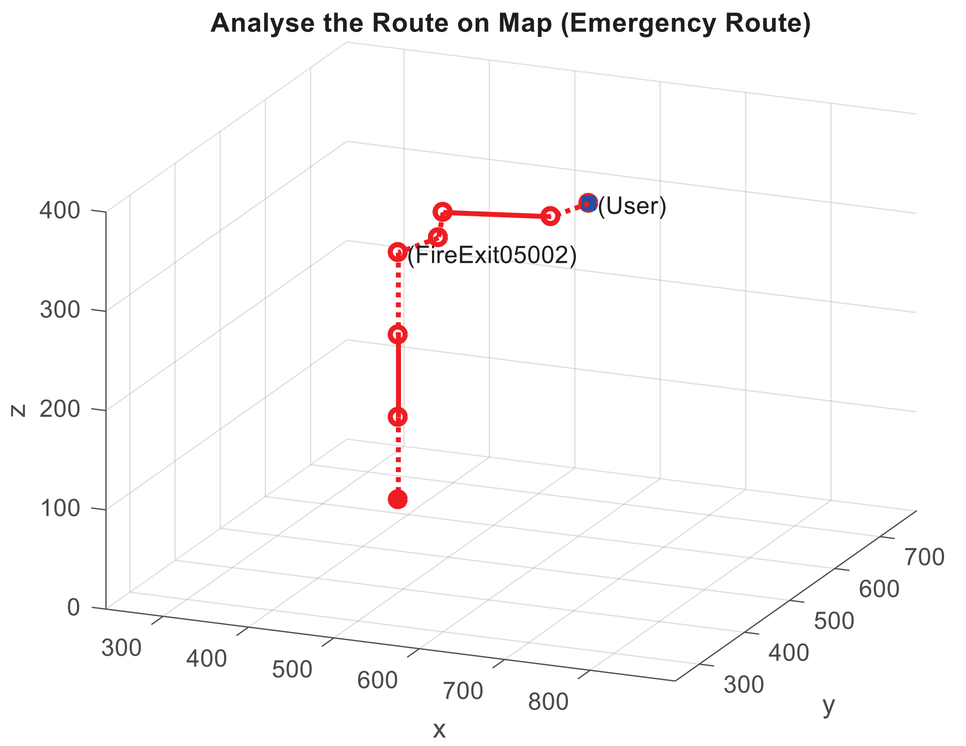
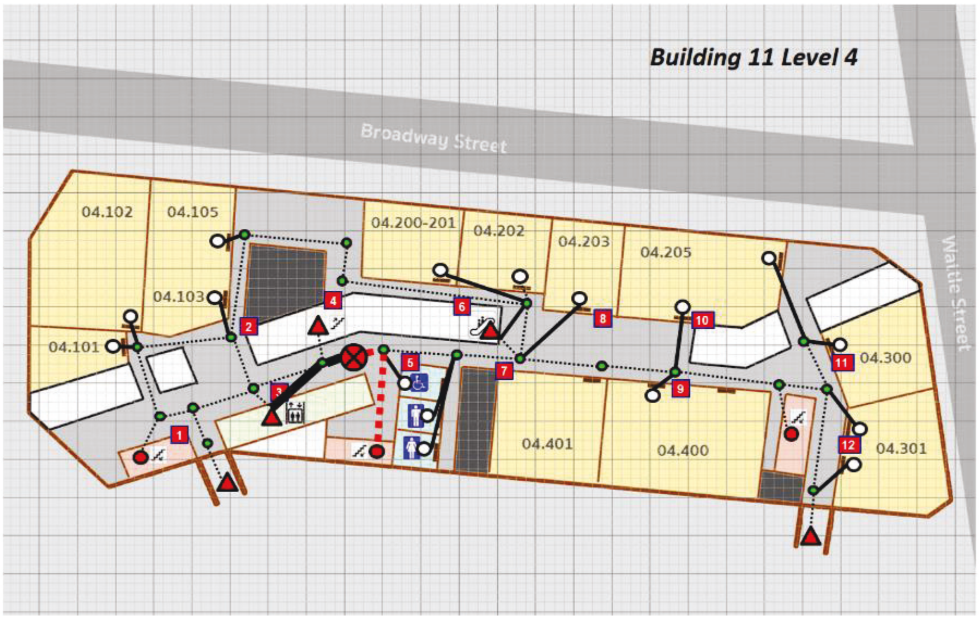


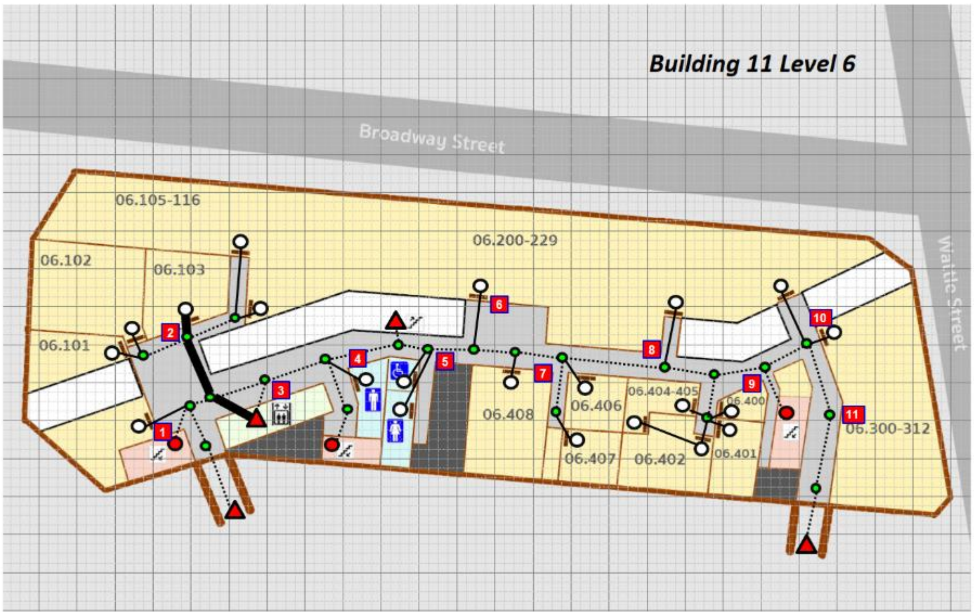
Figure 5.17. The emergency route from Level 5 to Room 11.04.401 on Level 4 (Case 2)

Test Case 3: FR_inBLD03 (Finding Route in Building 03)

Person *B* will be able to find the route from Level 4 to a room on Level 6. This person is set at the "user current position" on Level 4 in Building 11. The target room is Level 6 (Room.11.06.103). The route is shown in Figure 5.18. The expected route includes MN, SC04016, LK04001, LK05001, LK06001, SC06006, SC06002, and Room06103.

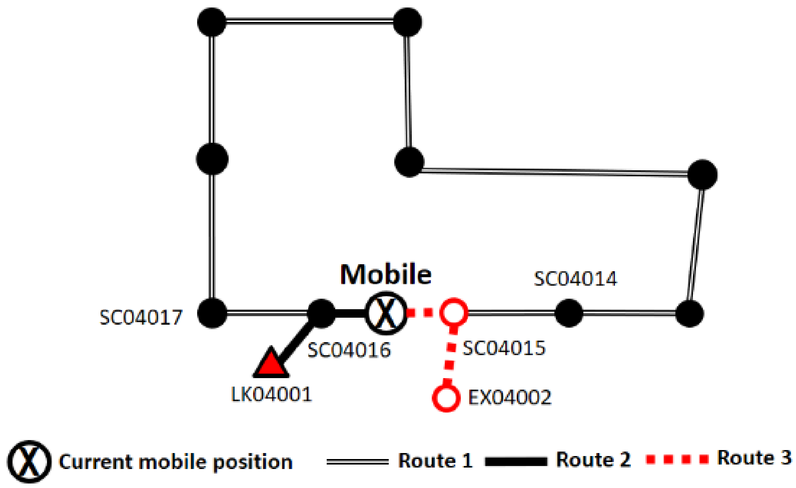


(a) Shows the map of Level 4 and route link to Level 6 (includes emergency route)

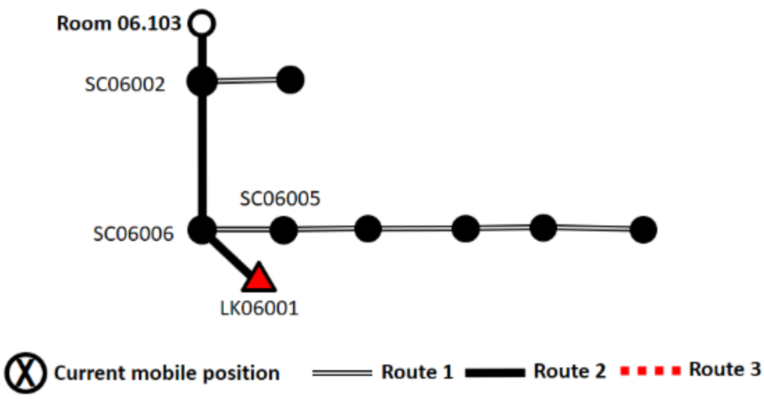


(b) Shows the map of Level 6 and the route link from Level 4

Figure 5.18 The route from Level 4 to Room 11.06.103 on Level 6 (Case 3)



(a)



(b)

Figure 5.19. The route node from Level 4 to Room 11.06.103 on Level 6 (Case 3)

The results of Test Case 3 is in Table 5.5. It shows both normal route and emergency route. This table details results of the experiment in Test Case 3.

Table 5. 5. Test Results for Test Case 3

	Test Case 3: FR_inBLD03 **Normal state**	**Test Case 3: FR_inBLD03** **Emergency state**
Route description	From Starting point to normal room door in the Level 4 to Level 6	From Starting point to emergency door in the Level 4 to Level 6
Building State	Normal	Emergency
Start point	***MN(519,522,255), at front of lifts and toilets, Level 4***	***MN(519,522,255), at front of lifts and toilets, Level 4***
Target point	***Room 06.103 Level 6***	***Emergency door Level 4 (2)***
Test Flow	Figure 5.18	Figure 5.18
[Expected result] **Passing nodes**	MN, SC04016, LK04001, LK05001, LK06001, SC06006, SC06002, Room06103	MN, SC04015, EX04002, EX02002
[Expected result] **True route array**	[MN, SC04016, LK04001, LK05001, LK06001, SC06006, SC06002, Room06103]	[MN, SC04015, EX04002, EX02002]
[Experiment Result] -Computed passing nodes	MN, SC04016, LK04001, LK05001, LK06001, SC06006, SC06002, Room06103 Figure 5.19	MN, SC04015, EX04002, EX02002 Figure 5.19

[Experiment Result] -Computed route array	[MN, SC04016, LK04001, LK05001, LK06001, SC06006, SC06002, Room06103] Figure 5.20, 5.21	[MN, SC04015, EX04002, EX02002] Figure 5.22
Result - Pass or Fail	Pass	Pass

The result of Test Case 3 is illustrated in Figure 5.20. User C starts from (519,537,255) in Level 5, the target room is Room06103 (274,597,421) in the 2-D map. The blue curve shows the route of user to find the room. The green line is linking from the 4th floor to the 6th floor (LK04001, LK05001, LK06001). The plots shows that the route is correct; the final accuracy to the target coordinates is 2 meters.

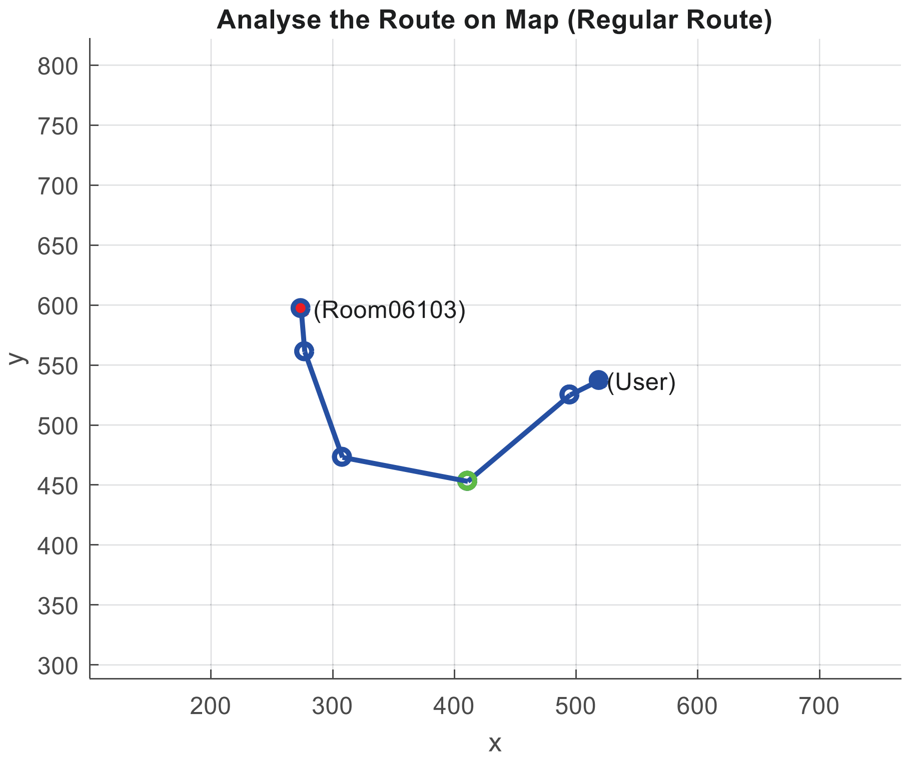


Figure 5.20. The normal route from Level 4 to Room 11.06.103 on Level 6 (Case 3)

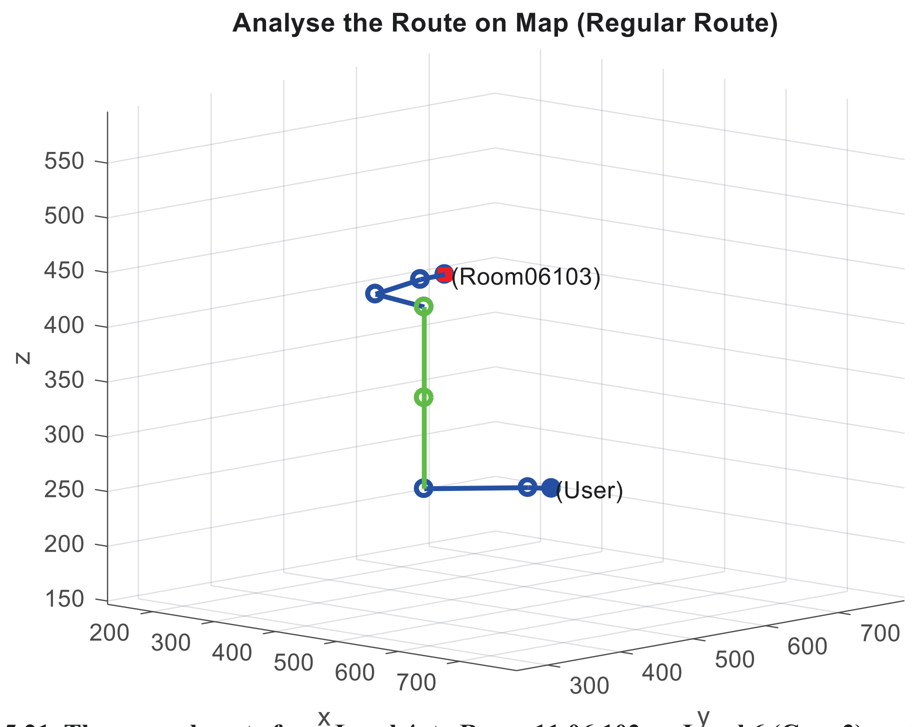


Figure 5.21. The normal route from Level 4 to Room 11.06.103 on Level 6 (Case 3) vertical view

Figure 5.22 illustrates the result of emergency route in test case 3. When the building has an emergency state, the emergency route navigates to FireExit04002 in Level 4.

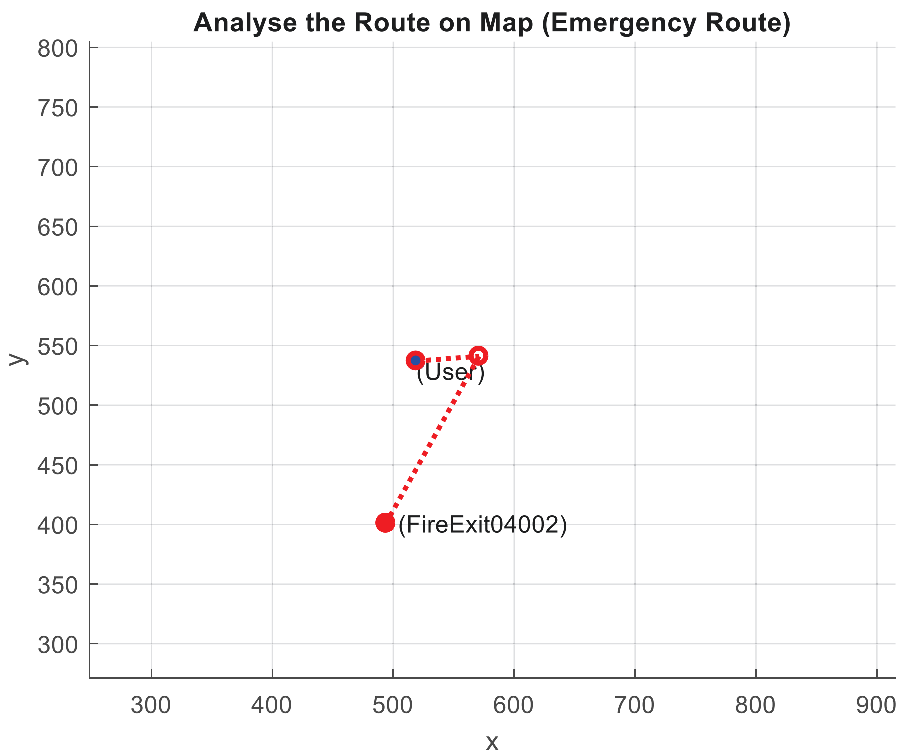


Figure 5.22 The emergency route from Level 4 to fire exit on Level 6 (Case 3)

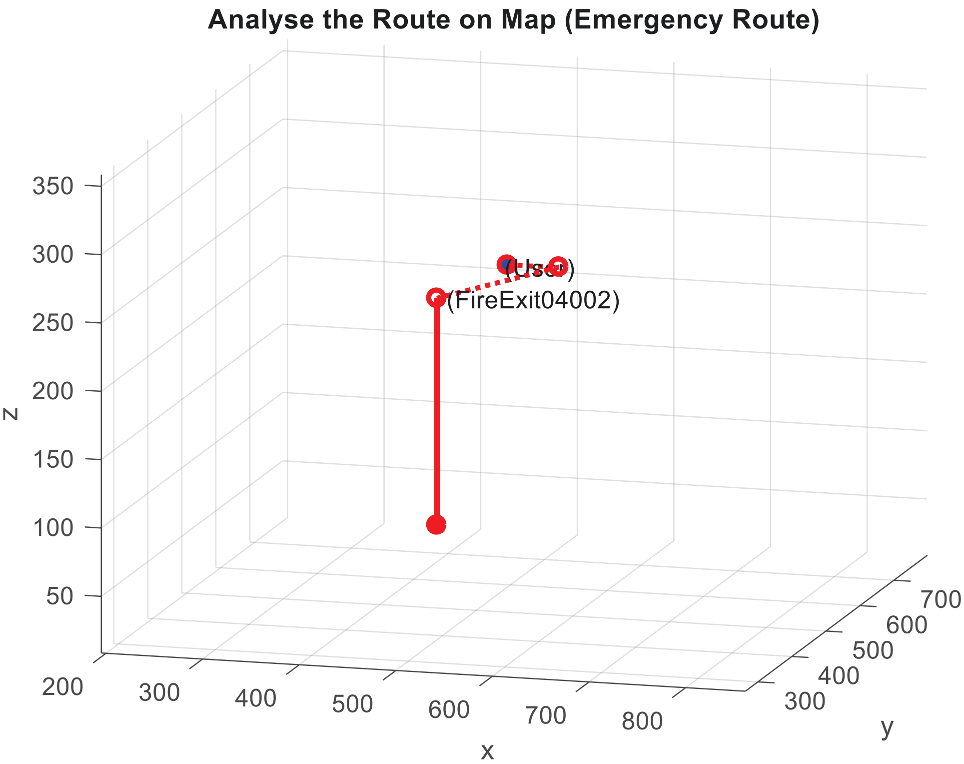


Figure 5.23 The emergency route from Level 4 to fire exit on Level 6 (Case 3) vertical view

In this thesis, the algorithm for analyzing the current position of user was tested 20 times with results shown in Figure 5.24.

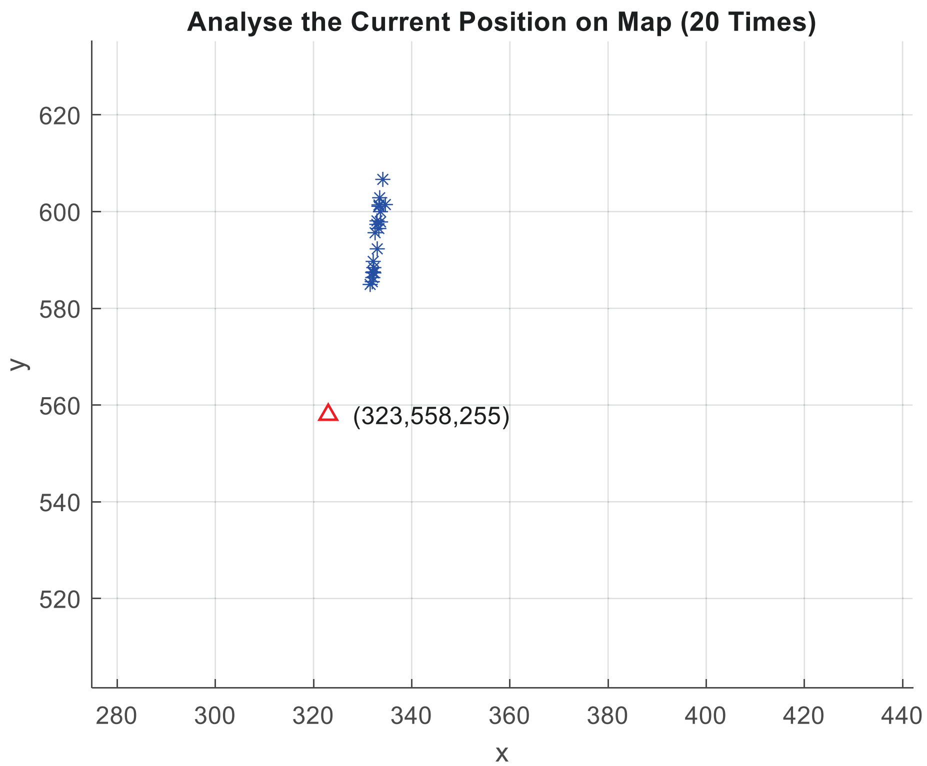


Figure 5.24 Example showing the calculation of the current mobile position with the real position

In Figure 5.25 the error distance is shown at each time of analysis.

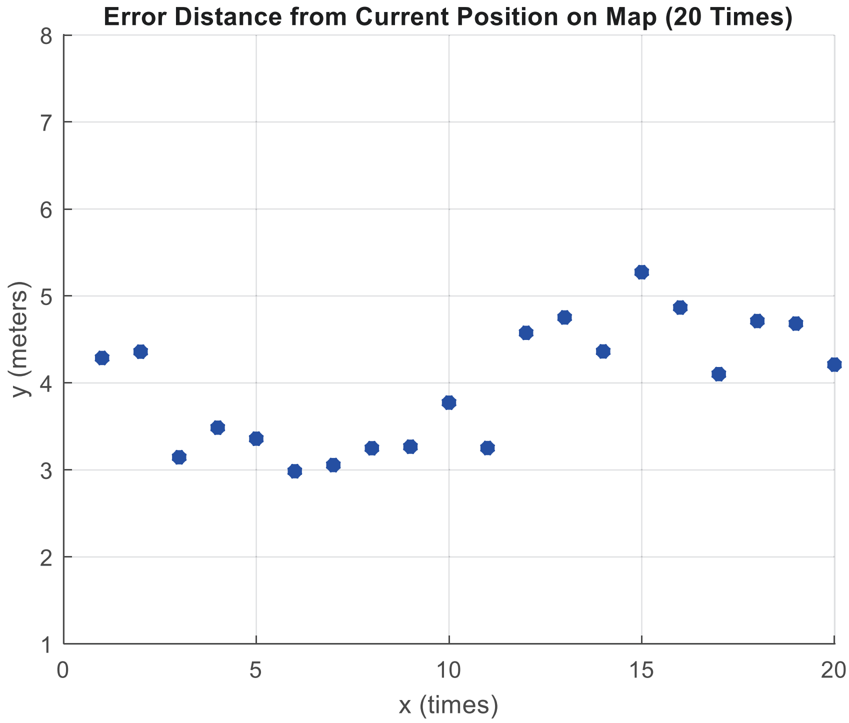


Figure 5.25 Error distance

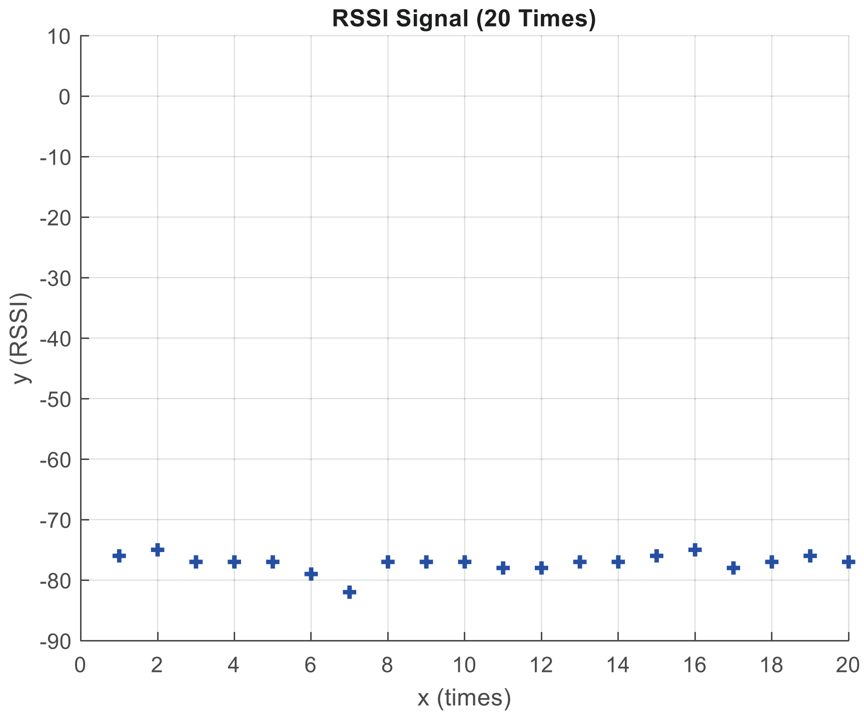


Figure 5.26 Range of RSSI signal in 20 measurements

5.4 Validation of the Multi-level Indoor Navigation Ontology for Finding Lost Property

5.4.1 Experimental design

The purpose of this experiment is to validate the multi-level indoor navigation ontology for finding lost property, using two people carrying smartphones to find lost objects in an iBeacon network in a multi-level building.

1) Background

UTS Building 11 is used for the experimental location in this thesis. It is a complex location because of its many floors and rooms in a complex layout. It includes elevators, escalators, and several sets of stairs (both fire stairs and regular stairs) for linking to different levels. This testing is designed and planned for use in this building. This testing uses iBeacon stickers which are attached to a valued object such as Laptop or bag. This experiment used two beacon types as was explained in Chapter 4.

Following the completion of the design of the Multi-level Indoor Navigation Ontology, it was applied to the navigation system inside the building. The experiment uses the data from the BLE devices.

Figure 5.27. Sticking iBeacon on the objects

2) Objectives

The test plan for the Multi-level Indoor Navigation Ontology for finding the lost property supports the following objectives:

- Identify nodes and features in the indoor navigation model that are required to be tested
- Describe the approach to testing the theory
- Development of a test approach
- Design the test case
- Specify Pass/Fail criteria

It is necessary for the objectives listed above to ensure the successful development of the stage of acceptance experiment.

3) Scope

This experiment is designed to demonstrate the route for finding lost property in the building in three cases. However, these tests have only used the regular situation route, not the emergency situation. These conditions follow the design outlined in chapter 4. The Multi-level Indoor Navigation Ontology for Finding the Lost Property is developed for multi-linking between the floors inside the building. It can be used for the route validation for the user, including travel along the same floor, to a lower level, or to a higher level.

4) Functional Requirements

The functional requirements for the ontology validations are:

Requirement 1: REQ_FLP01

Person A will be able to find Michael's wallet *(McWal01)* on Level 4 . This person is set at the "user current position" on Level 4 in Building 11. The target property is in a room on Level 4 (Room.11.04.200).

Requirement 2: REQ_FLP02

Person B will be able to find Emma's laptop (*EmmaLpt01*) in Zone 3 on Level 4 . This case sets the "user current position" on Level 5 in Building 11. The target property is Zone 3 on Level 4 .

Requirement 3: REQ_FLP03

Person C will be able to find Lex's iPad (*LxiPad01*) in room 11.07.200 in Level 7. This case sets the "user current position" on Level 4 in Building 11. The target property is a room of Level 7 (Room.11.07.200-217).

5) Test case design

The test cases in these experiments are as in the following table.

Table 5.6. Test case design

Requirement #	Test case #	Status #
1-REQ_FLP01	FLP_001- Shows route for finding the lost property on the same level	Normal
2-REQ_FLP02	FLP_002- Shows route for finding the lost property from a lower level to a higher level	Normal
3-REQ_FLP03	FLP_003- Shows route for finding the lost property from a higher level to a lower level	Normal

6) Test environments

- The hardware items needed in this experiment are:

  - *BLE devices* or iBeacons installed on the walls in the building, covering on each floor. The distance between each iBeacon is around 15 meters.

- - *Smartphone,* uses LG Nexus 5 mounted on a tripod for data collection . The software packages needed in this experiment are:

  - An *Android application* "iBeacon & Eddystone Scanner app." It is used to collect the signal information including UUID, Major ID, Minor ID, RSSI, and Power TX.

  - *Matlab R2016b*, this software will be used to validate the route for Multi-level Indoor Navigation of Ontology for Finding the Lost Property.

- The location used in this experiment is:

Building 11 of University Technology Sydney. This building has 12 floors and 4 basements. It is the home building of the Faculty of Engineering and Information Technology. The levels on the map represent the level of building in *z-value*. This thesis used levels 2 to 7 with Level 2=89, Level 3=172, Level 4 =255, Level 5=338, Level 6=421, and Level 7=504. They are the values for presentation on 3D building view on Matlab .

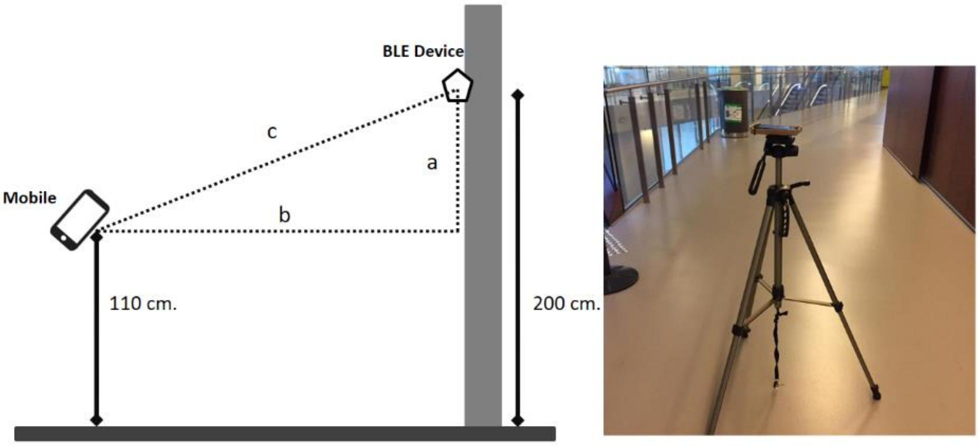


Figure 5.28. Setup device for experiment

5.4.2 Experimental results

Experiment of Finding Lost Property, result will only get 'Pass' and 'Fail' if the route can correctly set the route from the starting point to the target point as the expected result. It is considered "Pass". However, if the route result does not follow the expected result, it will get "Fail".

Test Case 1*: *FLP_001 *(*Finding Lost Property 01*)*

Person *A* will be able to find Michael's wallet (ID: *McWal01*) on Level 4 . This person is set as the "user current position" on Level 4 in Building 11. The target property *McWal01* is in a room on Level 4 (Room.11.04.200). The route is shown in Figure 5.29. The expected route includes MN,SC04017, SC04016, SC04015, SC04014, SC04013, SC04006, Room04200-201.

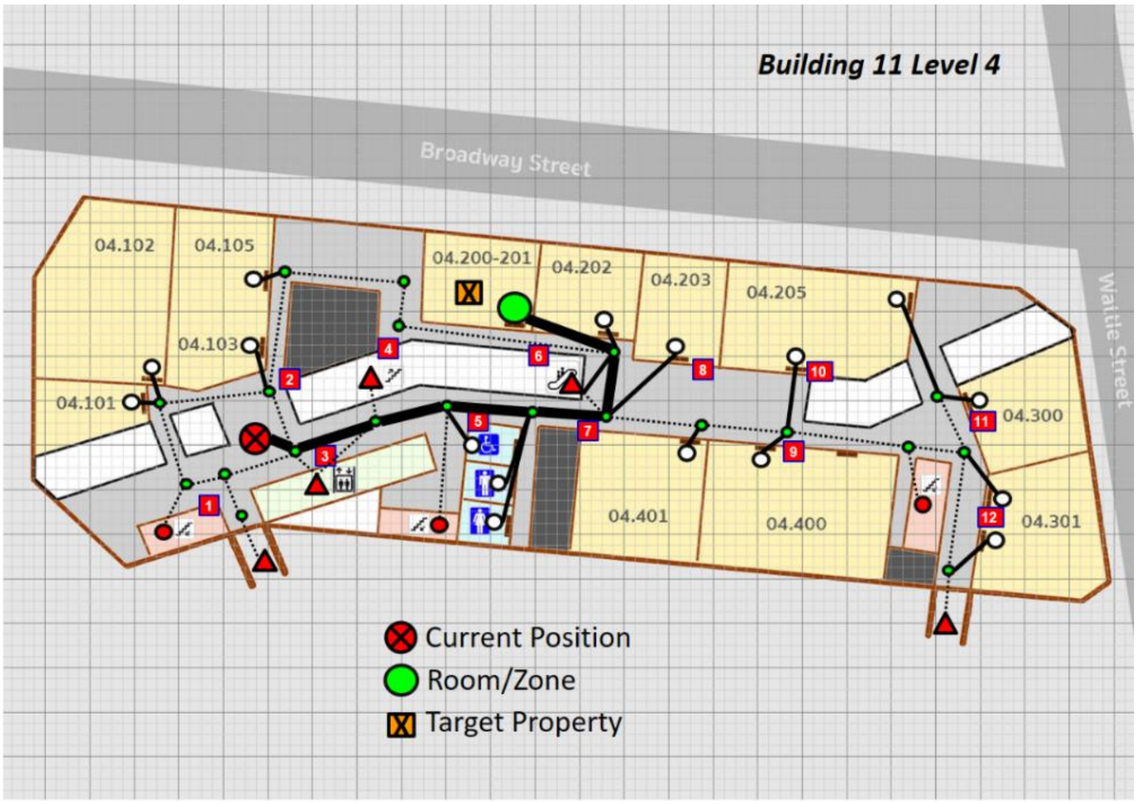


Figure 5.29. The route to Room 11.04.200 on Level 4 (Case 1)

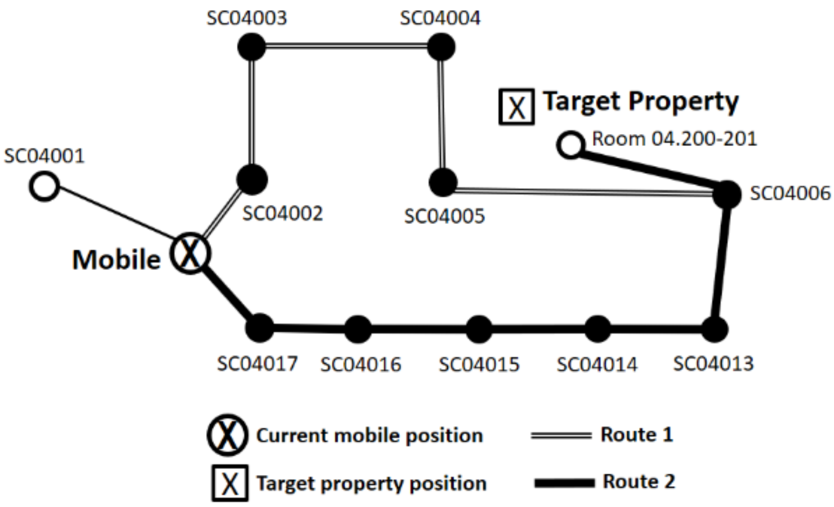


Figure 5.30. The node route to Room 11.04.200 on Level 4 (Case 1)

The experiment analyses the route which first checks the building status. This experiment focuses on the building in its normal situation. For this case, the expected route is "Route 2" in this case as shown in Figure 5.30. User starts from the current mobile position and follows the coordinates to the target property in Room 04.200-201. The route result was validated as in Table 5.7.

Table 5.7. Experiment result in Test Case 1

	Test Case 1: FLP_001 **Normal state**
Route description	From Starting point to normal room door in the same level – Level 4
Building State	Normal
Start point	***MN(324,555,255), sofa at front of lifts, Level 4***
Target property	***VP(590,366,255) in the room no. 04.200-201***
Target point or zone	***Room 04.200-201*** ***Level 4***
Test Flow	Figure 5.29
[Expected result] **Passing nodes**	MN,SC04017, ,SC04016, SC04015, SC04014, SC04013, SC04006, Room04200-201
[Expected result] **True route array**	[MN,SC04017, ,SC04016, SC04015, SC04014, SC04013, SC04006, Room04200-201]
[Experiment Result] -Computed passing nodes	MN, SC04017, SC04016, SC04015, SC04014, SC04013, SC04006, Room04200-201 Figure 5.30
[Experiment Result] -Computed route array	[MN, SC04017, SC04016, SC04015, SC04014, SC04013, SC04006, Room04200-201] Figure 5.31
Result - Pass or Fail	Pass

The result of Test Case 1 is illustrated in Figure 5.31. User *A* starts from (324,504,255), the target room is Room04200-201 where there is lost property and is shown on the 2-D map. The blue curve shows the route followed by the user to find the room. The plots show that the route is correct; the final accuracy to the target coordinates is 2 meters.

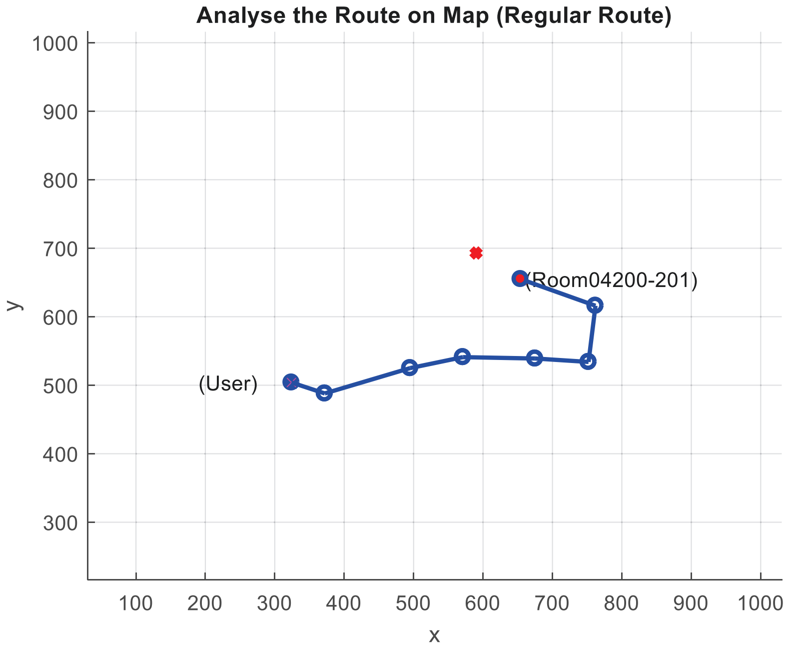
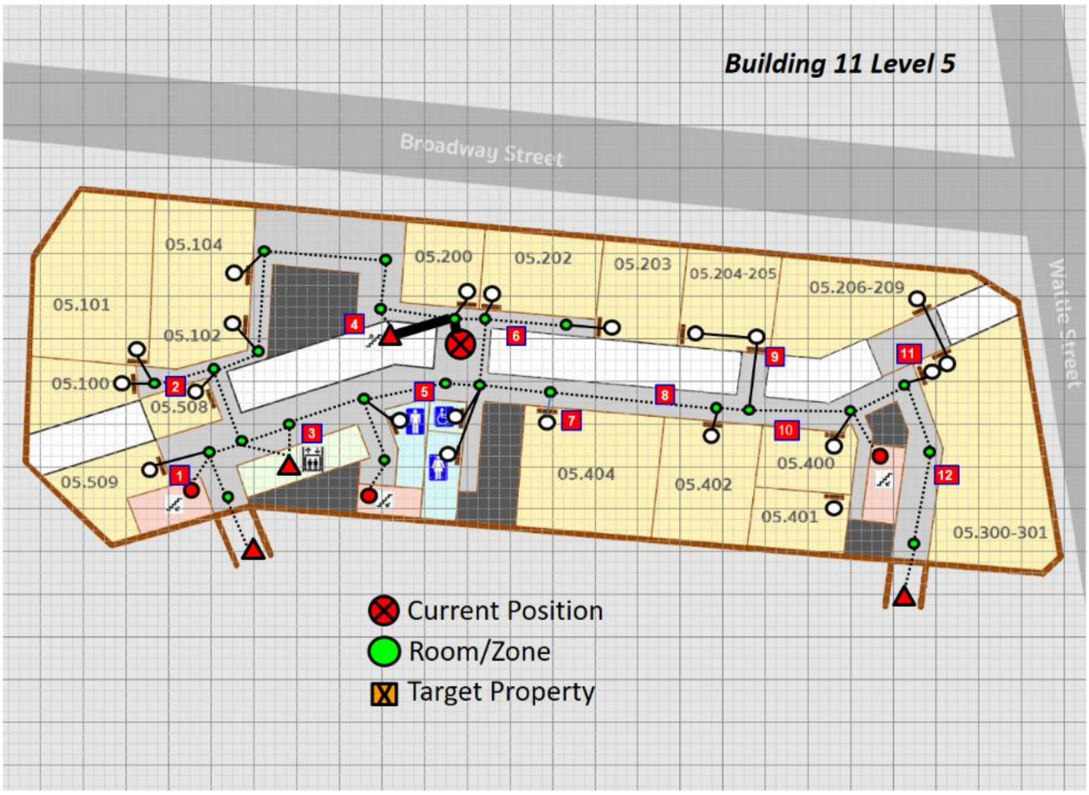


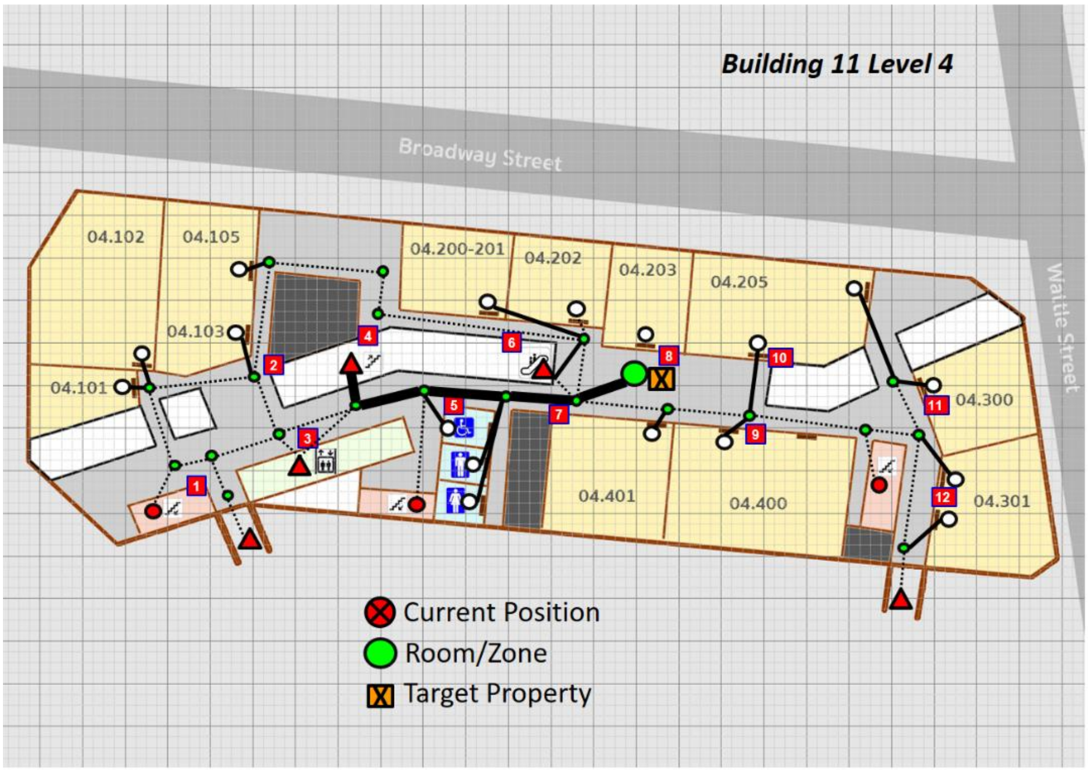
Figure 5.31. The route of validation on Matlab, from current position to Room 11.04.200 on Level 4

Test Case 2: FLP_002 (Finding Lost Property 02)

Person *B* will be able to find the Emma's laptop (*EmmaLpt01*) in Zone 3 in Level 4 . This person starts from escalators in Level 5. This case is set the "user current position" on Level 5 in Building 11. The target property is Zone 3 of Level 4 as shown in Figure 32. The expected route includes MN, SC05007, LK05002, SC04016, SC04015, SC04014, SC04013, Zone0403.



(a) Shows the map of Level 5 and route link to Level 4 (includes the emergency route)



(b) Shows the map of Level 4 and the route to the target place

Figure 5.32. The route from Level 5 to Zone 3 on Level 4 (Case 2)

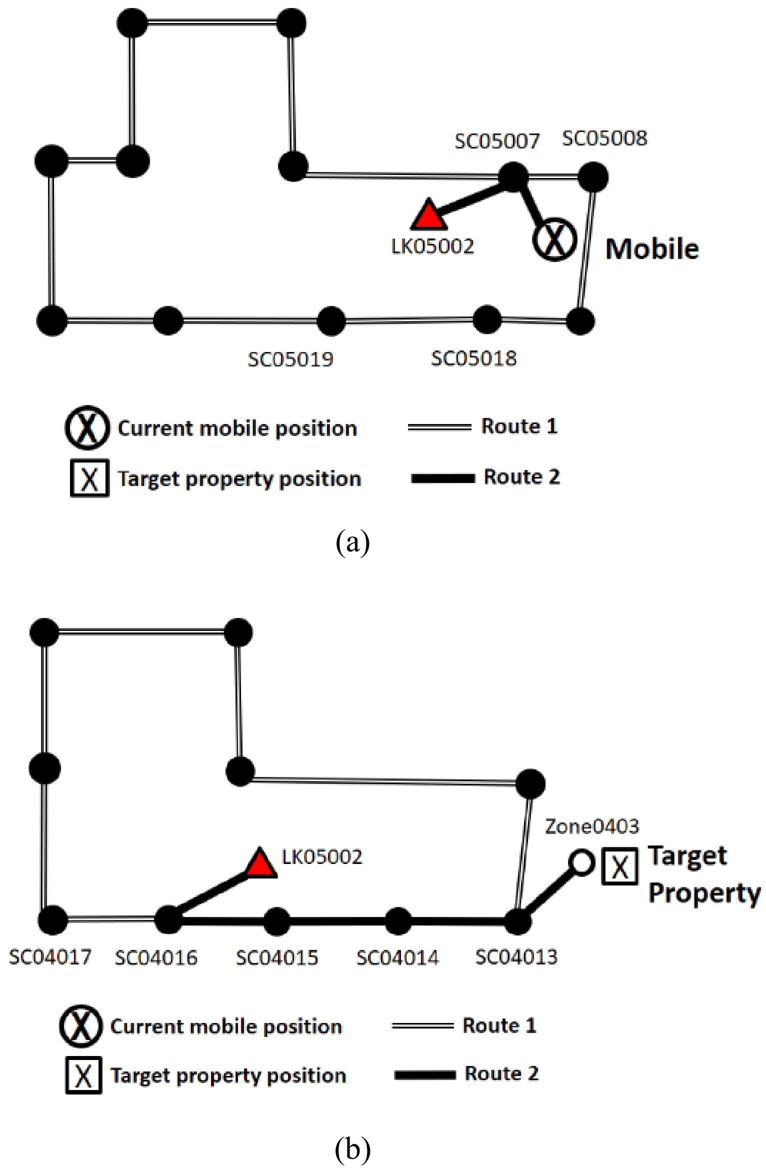


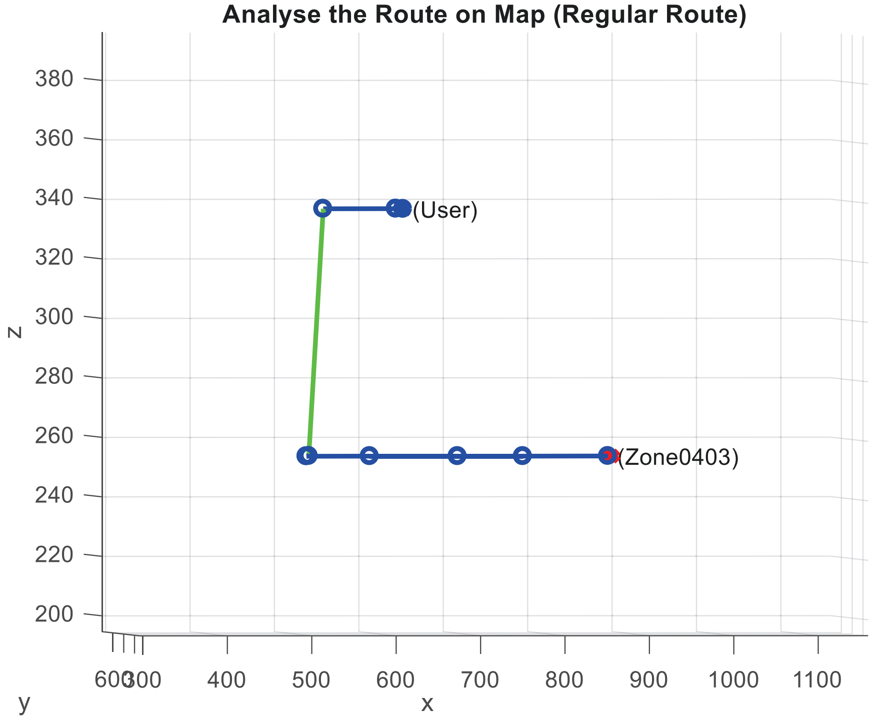
Figure 5.33. The node route from Level 5 to Zone 3 on Level 4 (Case 2)

The experiment analyses the route after checking the building status. If the building is in its normal situation, the route result is validated as shown in Table 5.8.

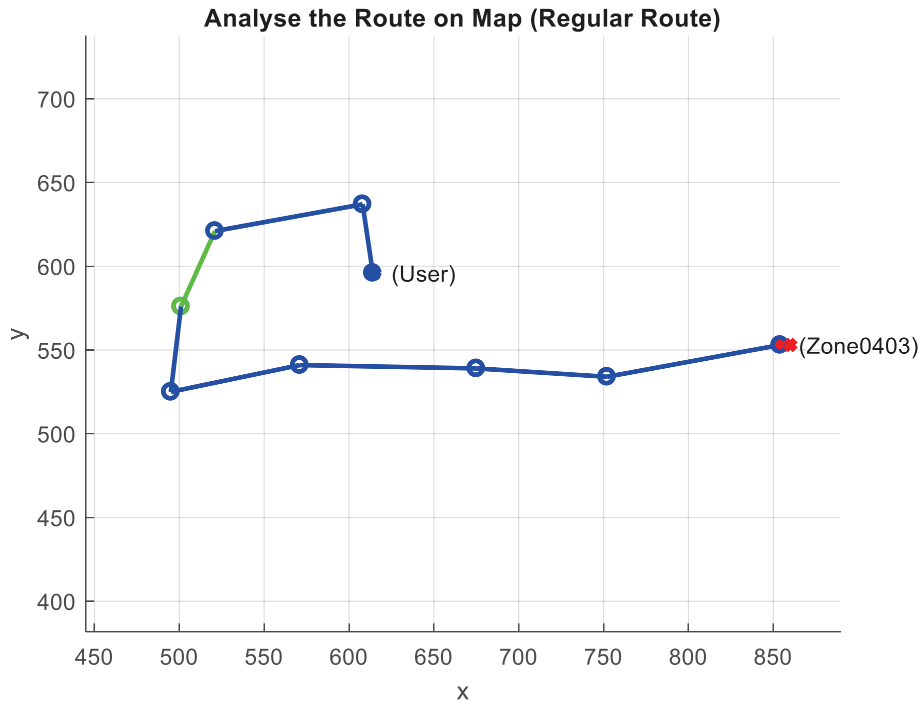
Table 5.8. Experiment result in Test Case 2

	Test Case 2: FLP_002 **Normal state**
Route description	From starting point to normal room door in Level 5 to Level 4
Building State	Normal
Start point	***MN(614,463,338), front of toilets, Level 5***
Target property	***VP(860,506,255) in the lobby zone Level 4***
Target point or zone	***Zone04.03 Level 4*** ***(854,506,255)***
Test Flow	Figure 5.32
[Expected result] **Passing nodes**	MN, SC05007, LK05002, SC04016, SC04015, SC04014, SC04013, Zone0403
[Expected result] **True route array**	[MN, SC05007, LK05002, SC04016, SC04015, SC04014, SC04013, Zone0403]
[Experiment Result] -Computed passing nodes	MN, SC05007, LK05002, SC04016, SC04015, SC04014, SC04013, Zone0403 Figure 5.33
[Experiment Result] -Computed route array	[MN, SC05007, LK05002, SC04016, SC04015, SC04014, SC04013, Zone0403] Figure 5.34
Result - Pass or Fail	Pass

The result of Test Case 2 is illustrated in Figure 5.34. User B starts from (614,596,338), the target room is Zone 3 (854,553,255) Level 4 where the objects are as shown on the 2-D map. The blue curve shows the route for the user to find the room. The plots shows that the route is correct; with final accuracy to the target of 2 meters. The green line shows the link to different floor and the red dot is the location of the target object.



(a)

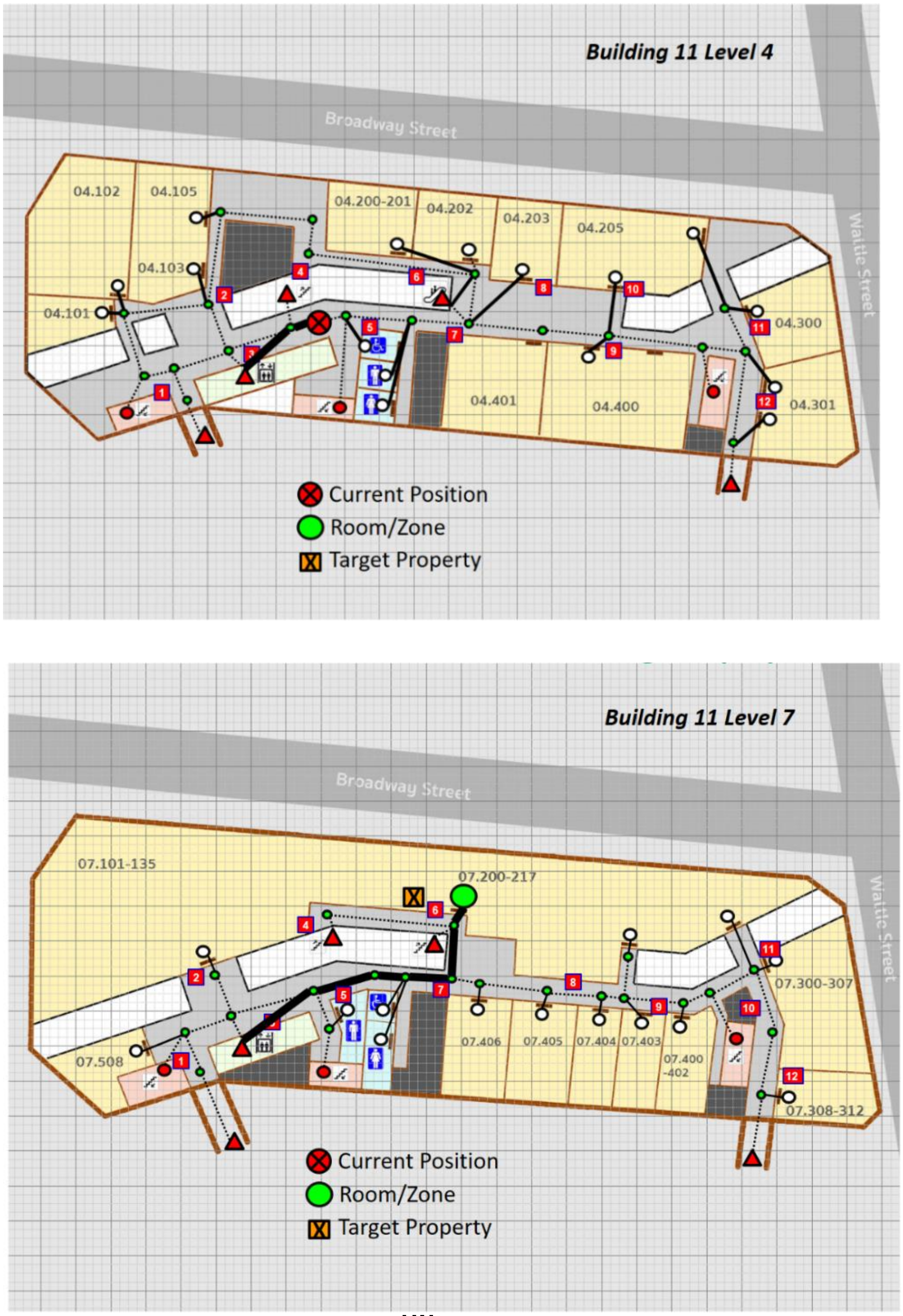


(b)

Figure 5.34. The normal route of validation from Level 5 to Zone 3 on Level 4 (Case 2)

Test Case 3: FLP_003 (Finding Lost Property 03)

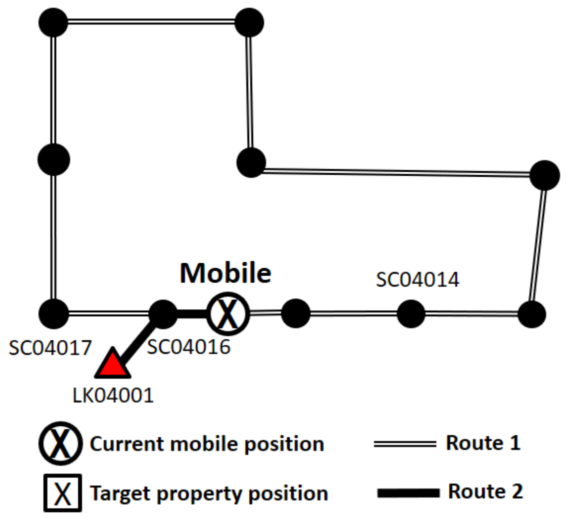
Person *C* will be able to find Lex's iPad (*LxiPad01*) in room 11.07.200 in Level 7. This person starts from in front of the lifts on Level 4 . This case is set as the "user current position" on Level 4 in Building 11. The target property is in a room on Level 7 (Room.11.07.200-217).



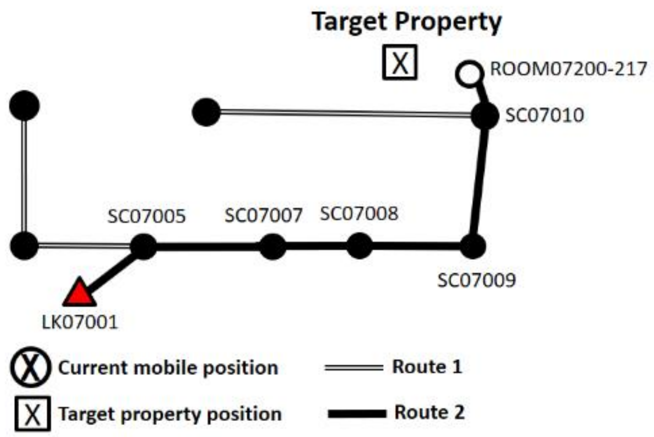
(a)

(b)

Figure 5.35. The route from Level 4 to Room.11.07.200-217 on Level 7 (Case 3)



(a)



(b)

Figure 5.36 The node route from Level 4 to Room.11.07.200-217 on Level 7 (Case 3)

The experiment analyses the route after checking the building status. If the building is in its normal situation, the route result as validated is shown Table 5.9.

Table 5.9. Experiment result in Test Case 3

	Test Case 3: FLP_003 **Normal state**
Route description	From Starting point to normal room door in the Level 4 to Level 7
Building State	Normal
Start point	***MN(519,522,255), at front of lifts and toilets, Level 4***
Target property	***VP(651,385,255,504) in the room no. 07.200-217 Level 7***
Target point or zone	***Room 07.200-217*** ***Level 7 (733,392,504)***
Test Flow	Figure 5.35
[Expected result] **Passing nodes**	MN, SC04016, LK04001, LK05001, LK06001, LK07001, SC07005, SC07007, SC07008, SC07009, SC07010, ROOM07200-217
[Expected result] **True route array**	[MN, SC04016, LK04001, LK05001, LK06001, LK07001, SC07005, SC07007, SC07008, SC07009, SC07010, ROOM07200-217]
[Experiment Result] - Computed passing nodes	MN, SC04016, LK04001, LK05001, LK06001, LK07001, SC07005, SC07007, SC07008, SC07009, SC07010, ROOM07200-217 Figure 5.36

[Experiment Result] - Computed route array	[MN, SC04016, LK04001, LK05001, LK06001, LK07001, SC07005, SC07007, SC07008, SC07009, SC07010, ROOM07200-217] Figure 5.37
Result - Pass or Fail	Pass

The result of Test Case 3 is illustrated in Figure 5.37. User C starts from (519,537,338), the target room is Room07200-217 Level 7 where the objects are as shown on the 2-D map. The blue curve shows the route for the user to find the room. The plots shows that the route is correct; with final accuracy to the target of 2 meters . The green line shows the link to different floor and the red dot is the location of the target object.

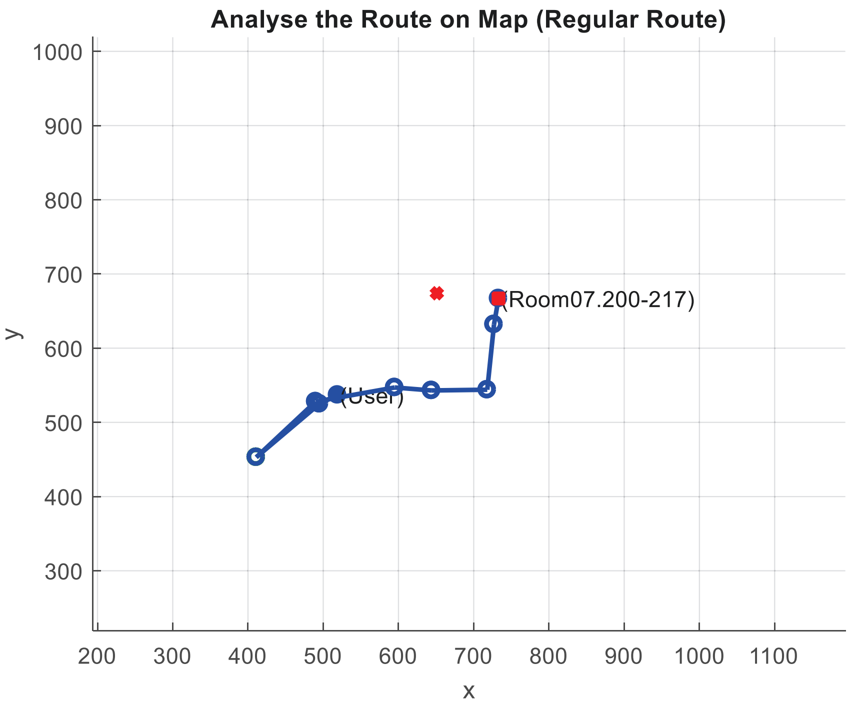


Figure 5.37. The validation of normal route from Level 4 to Room.11.07.200-217 on Level 7 (Case 3)

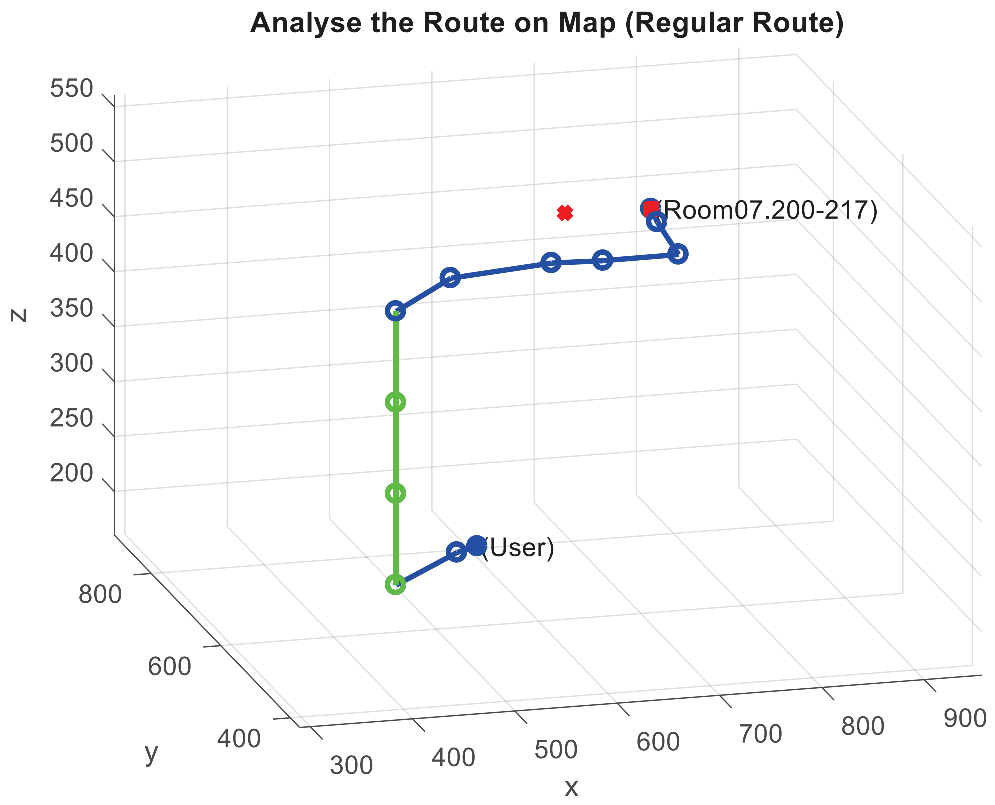


Figure 5.38. The validation of normal route from Level 4 to Room.11.07.200-217 on Level 7 (Case 3) vertical view

5.5 Discussion

The experiments testing the two theories produced the results as shown in the above sections, tested in a real area of a building. The first experiment is the validation of the Multi-level Indoor Navigation Ontology for Location-based Service, designed for finding an optimal route in both the normal state and an emergency state inside a building. The second experiment is the validation of the Multi-level Indoor Navigation Ontology for Finding Lost Property in the building.

The results are discussed as follows:

1). Validation of the Multi-level Indoor Navigation Ontology for Location-based Service

This experiment was conducted with three test cases for two situations, the normal or regular situation and an emergency situation.

Test case 1 : Movement in same level

In this case *FR_inBLD01*, user starts from the front of lifts on Level 4 and the target room is Level 4 (Room.11.04.202). This route case include 8 nodes include MN, SC04017, SC04016, SC04015, SC04014, SC04013, SC04006, and Room04202. The total real distance is around 46 metres. The result of an experiment in the regular situation is "pass", because it can show the route to the required target place with adequate accuracy. A user can use this route for walking to the chosen destination. In addition, the demonstration in the emergency state was also "pass," as it could provide a route to the exit door on Level 4 (FireExit04001).

However, the distance may show differences each time as the estimation of the current position or "MN" node in the building has an accuracy of 2-3 meters from the actual or real location.

Test case 2: Movement to a lower level

In this case *FR_inBLD02*, the user starts from the front of the escalators on the Level 5 and the target room is Level 4 (Room.11.04.401). This route case includes 9 nodes which includes MN, SC05007, LK05002, SC04016, SC04015, SC04014, SC04013, SC04012, and Room04401. The total real distance is around 30 meters. The result of an experiment is "pass" because it can show the route to the required target room with sufficient accuracy. A user can follow this route for walking to the chosen destination. In addition, the demonstration in the emergency state was also "pass," as it could provide a route to the exit door on Level 5 (FireExit05002).

However, the distance may show differences each time as the estimation of the current position or "MN" node in the building has an accuracy of 2-3 meters from the actual or real location.

Test case 3: Movement to a higher level

In this case *FR_inBLD03*, the user starts from in front of the escalators on the Level 4 and the target room is Level 6 (Room.11.06.103). This route case has 8 nodes including MN, SC04016, LK04001, LK05001, LK06001, SC06006, SC06002, and Room06103. The total real distance is around 30 meters. The result of an experiment is a "pass" because it can show the route to the chosen target. A user can use this route for walking to the destination with sufficient accuracy. In addition, the demonstration in the emergency state was also “pass”, as it could provide a route to the exit door on Level 4 (FireExit04002).

The result of the validation experiments, using a weighted centroid localization algorithm based on improved RSSI ranging, has less positioning error and higher positioning accuracy. However, the distance may show differences each time as the estimation of the current position or “MN” node in the building has an accuracy of 2-3 meters from the actual or real location.

2). Validation of the Multi-level Indoor Navigation Ontology for Finding Lost Property

This experiment was designed with three test cases. The valued objects had the sticky iBeacons attached on them. They were placed in different locations in the building for each test, within the range of the signals from the iBeacons.

Test Case 1: Movement on the same level

In this case, the user starts from in front of the escalators on the Level 4 and the target property is in the Room.11.04.200-201 on Level 4 . This route case include 8 nodes MN, SC04017, SC04016, SC04015, SC04014, SC04013, SC04006, and Room04200-201. For the test on *FLP_001,* the result of an experiment is a “pass” because it can show the route to the required target room with sufficient accuracy. A user can follow this direction and can walk to the room. However, the distance may show differences each time depending on the estimation of the current position or “MN” node in the building.

Test Case 2: Movement to a lower level

The user starts from in front of the escalators on Level 5 and the target object is in the zone (Zone0403) on Level 4 . This route case includes 8 nodes MN, SC05007, LK05002, SC04016, SC04015, SC04014, SC04013, and Zone0403. For the test on *FLP_002,* the result of an experiment is “pass” because it can show the route to the required target room with sufficient accuracy. A user can follow this direction by walking to the room. However, the distance may show differences each time depending on the estimation of the current position or “MN” node in the building.

Test Case 3: Movement to a higher level

The user starts from in front of the escalators on Level 4 and the target object is in the room (ROOM07200-217) on Level 7. This route case includes 12 nodes MN, SC04016, LK04001, LK05001, LK06001, LK07001, SC07005, SC07007, SC07008, SC07009, SC07010, and ROOM07200-217. For the test on *FLP_003,* the result of an experiment is "pass" because it can show the route to the required target room with sufficient accuracy. A user can follow this direction for walking to the room. However, the distance may show differences each time depending on the estimation of the current position or "MN" node in the building.

The result of the validation experiments, using a weighted centroid localization algorithm based on improved RSSI ranging, has less positioning error and higher positioning accuracy. However, the distance may show differences each time as the estimation of the current position or "MN" node in the building has an accuracy of 2-3 meters from the actual or real location.

Chapter 6
Conclusion

6.1 Summary of the thesis

More than 90 percent of human activities occur in indoor environments. A need for indoor navigation requires Location-Based Services (LBS). The LBS should be able to assist people to find the best route inside a building under all circumstances and with high reliability, supporting users to navigate to all indoor spaces on every level of the building. The current research has been focusing on technologies and applications for LBS. There has been little work on a LBS standard. This research contributes to a new LBS standard using ontology theory. Two ontologies are developed in this thesis. Firstly, a Multi-level Indoor Navigation Ontology is developed. This ontology builds a standard for LBS in multi-level indoor environments and considers the building status in emergency and normal states for user navigation. This ontology is designed to present environmental attributes including the location nodes, connection points, and building status in a multi-level building. The indoor location nodes with the location information allow navigation within the building, with connection points which can separate the map zones and the building floors. Secondly, an ontology for finding lost property in a multi-level indoor space is developed as a sub-level standard in LBS applications. These two ontologies are validated using experiments using an iBeacon network in a high-rise building.

In this thesis, the theory of indoor navigation was developed to support researchers or developers. Using their smartphone, a user should be able to navigate from their current position to their desired location using the task ontology developed for the building. This research studied the use of BLE devices or iBeacons to support the analysis of location in an indoor environment. The iBeacons were set up in the building for data collection for indoor navigation validation.

The study has the following objectives:

1) Develop Multi-level Indoor Navigation Ontology for Location-based Services

The theory was designed using an indoor navigation ontology with a specific ontology for analyzing a route inside a building, thus contributing to the indoor navigation model.

This design will be better able to support indoor navigation under all situations inside the building. The model is designed to provide indoor localization information, which is compatible with the use of Bluetooth devices, to determine the user's current position. This ontology model contributes to a new standard for indoor localization information for LBS indoor navigation. Indoor navigation is to function for LBS with high assurance, as one of its quality requirements. As well as working under normal situations, the LBS should still work in emergencies, such as fires, building power shut downs.

2) Develop a Multi-level Indoor Navigation Ontology for Finding Lost Property

This thesis develops a dynamic indoor space model and technology to support the finding of lost property in an indoor environment. The various contexts are considered for indoor searching such as the context of search, location information, intent or words. The designing of the ontology is fundamental for conducting an indoor search as it can improve the efficiency of searching and provide the object's location with higher accuracy. The design was validated to the theory of an indoor navigation system which a software developer can apply to developing an indoor navigation system on their smartphone.

The thesis has successfully tested the effectiveness of these theories. The results of testing the two theories in this thesis were positive or "pass" because they could show the route to the required target location. All routes created in the cases studied were able to show the direction for the user to take; even though the total distance in each case may be missing, it does not affect the user's decision.

6.2 Main contributions

The main contribution of the thesis is the development of theories for indoor navigation applications on a smartphone using an indoor navigation ontology. The main contributions of this thesis are summarised as follows:

- The development of a multi-level indoor navigation ontology for LBS

  The multi-level indoor navigation ontology for location-based services is developed for indoor navigation. The theory is primarily developed in this thesis which can be applied to other applications. The multi-level indoor navigation ontology is useful for development in many situations. It is a new concept for development of indoor navigation mobile applications because the approach is flexible to apply. Ontology design can contribute to a new standard for indoor localization information for LBS indoor navigation. Indoor navigation is the functions for LBS with high assurance, one of its quality requirements. As well as working under normal situations, the LBS should still work in emergencies, such as fires, building power shut downs. As a result, it has been shown that this ontology design can lead to improved indoor navigation development using smartphones.

- The development of the indoor navigation ontology for finding lost property

  This theory is the second theory which is adapted from the multi-level indoor navigation ontology for location-based services. This theory will support the finding of an object inside the building. This technique uses the two iBeacon types to help with the algorithm. It develops a dynamic indoor space model and technology to support the finding of lost property in an indoor environment. The various contexts are considered for indoor searching such as the context of search or location information. The designing of the ontology is fundamental for conducting an indoor search as it can improve the efficiency of searching and provide the object's location with a higher accuracy.

- The development of a node structure for an indoor environment in a multi-level building

  This thesis uses the concept of a 'node' to be the connection with other positions. The node includes the information which applies to indoor navigation; these nodes are designed to be flexible enough to be used under most situations including normal and emergency situations inside the building. Design nodes on the position of a map show both route and all useful places. The ontologies developed are beneficial for the development of the indoor navigation and are meant to encourage future work.

  Moreover, the location node includes the three values (x, y, z) for the specific position on a floor so it can be applied on different floors and the user can see the map with a 3D view on the smartphone.

- The development of how to link the building space for connected nodes for LBS

  This thesis shows how to link to other coordinates, zone areas, or different floors. The node provides advantages in allowing connections to other positions inside the building. Furthermore, this linking design may provide a method for connecting to other buildings for indoor navigation. When there are many buildings in the same area, this model can link to all buildings using these nodes.

- The development of a route array algorithm for multi-level building navigation

The route information is one of the important contributions of this thesis because it allows the user to navigate to the chosen target. The route array is the variable sent to the mobile application for processing to provide the direction to the user. Each route array includes the start position or current user's position, as well as the coordinates for travelling and the chosen destination.

- The development of a multi-level route finding algorithm for LBS for emergency and regular situations inside a building

The Multi-level Indoor Navigation Ontology was designed for validation in the first theory. It was developed for use in two situations; an emergency situation and a regular situation. This approach has one particular advantage of the ontology design for every node in this thesis. Every node has the status to monitor the situation, set by using "On/Off" for describing the state of the building. Therefore, when the algorithm checks the node status, it interprets the current condition and analyzes the route for the user for the correct situation. This approach can apply to other situations, circumstances, or events such as the walkway of disabled, robot way, or custom route (admin sets the path for some events). The developer needs to focus on node design for determining the direction on the real map before beginning the development. This will lead to more efficient indoor navigation.

- The demonstration of indoor navigation for LBS using iBeacon Bluetooth devices

In this thesis, the indoor navigation theories were validated using the Matlab application for presenting the route in a multi-level building and validating using the data collected from the multiple iBeacons, attached to the walls on each floor of the building. The demonstration is presented in 3D and shows the route from starting point to target place.

6.3 Discussion of the research questions

6.3.1 Research questions

The following research questions have been established:

Research question 1: What are the ontology design classes for indoor navigation?

This research developed indoor navigation theories which consist of a travel ontology design including accurate determination of indoor locations using BLE sensors. The ontology was developed for improving the knowledge of the constraints to travelling. The ontology design uses the concept of nodes as the coordinates for indoor navigation. All classes contribute to support indoor navigation development and are flexible enough to apply to a general building design.

Research question 2: What development of a theory for indoor navigation using ontology and devices is necessary?

The ontology is designed to be efficient to develop, and BLE devices are used for indoor positioning in this thesis because of their ready availability and low cost compared to other techniques. They are easy to set up in the building and a smartphone can easily receive the signal from them. The theory in this thesis helps to improve indoor navigation and can be adapted to other buildings using this approach.

6.3.2 Discussion

In the literature review, this thesis identifies that this new contribution would provide improvement over other approaches.

The main gaps found in the literature review that this thesis will improve upon are as follows. Firstly, semantic location in an indoor navigation model uses static information and dynamic information, but this model is applied only to a map of one floor inside the building. In this thesis, the building data is described by nodes for supporting the navigation. This information can help to improve the indoor navigation system using a smartphone, especially the dynamic information which can lead to real-time changes to update the route. The complete data used for analyzing the route is dependent on the correct design structure. This thesis has designed the classes of ontology to correspond to development needs of the indoor navigation system.

Secondly, although the OntoNav model was presented as being able to link with other floors in a building, the ontology of OntoNav addresses only the linking of different levels in a building - users still need to select the path rule for travel and the restrictions on the route may be difficult for maintenance. This approach was adapted for use in this thesis, by linking to different floors of the building using the node concept. In this thesis, all nodes have been designed with the information necessary to connect to the different levels of a building or area or zone and can be developed to all situations in the building. Two situations were tested in this thesis; however, the approach can be applied to many situations in the future.

Finally, LotTrack used RFID and ultrasound technology to support autonomous navigation in the indoor space and develop a tracking system. RFID in buildings will be a large investment. Other, less expensive, Bluetooth devices have become the tool of choice for the indoor navigation system in this thesis. This approach can improve indoor navigation and is significantly cheaper to maintain than RFID. The installation of BLE devices to cover the whole building is beneficial and can make indoor navigation more widespread.

6.4 Future work

The theories developed in this thesis may need improvements for efficient indoor navigation. The enrichment of ontology is one of the next steps that can be taken. The future work in the area of extensions to the navigation includes contexts and enriched semantics considerations, as well as the addition of a rotation scheme contributing to route instructions. One area that needs more work is the integration of the constructed navigation graphs with outdoor networks or with other buildings.

In future work, some further information can be added to each node (especially for specific details of the node) to help people learn and easily remember the space and paths, since this is the critical part that can make the mobile guidance device helpful and practical for users. Also, meaningful statistical comments can be attached to particular decision nodes and landmark nodes obtained by analyzing past users' reviews and comments.

Furthermore, the pattern of attaching the iBeacons on the walls may be an important factor in improving the distance measurements obtained from BLE devices. Better precision on the calculation of distances may help in some situations, for example, for the visually impaired.

In case the building is crowded, the work can be enhanced to provide different routing for different users with the same origin and destination to avoid congestion.

Finally, the normal situation and emergency situation were presented as examples of indoor navigation in this thesis, where all nodes had the status to support the route analysis. The approach may be applied to other situations, for example, analyzing routes more appropriate for users with disabilities, or for robots.

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Appendix A

iBeacon Datasheet

Table A.1. Estimate iBeacon datasheet

	Location UWB Beacon	Location Beacon	Proximity Beacon	Sticker Beacon	Video Beacon
Battery life	5 years	5 years	2 years	1 years	Endless (USB-powered)
Range	200 meters	200 meters	70 meters	7 meters	10 meters
Thickness	27 mm	24 mm	17 mm	6 mm	14 mm
iBeacon™ or Eddystone™ packets	8 simultaneously	8 simultaneously	1 at a time	1 at a time	2 simultaneously
Additional Packets	connectivity, telemetry, user-defined	connectivity, telemetry, user-defined	connectivity, telemetry	connectivity, nearable with telemetry	connectivity, telemetry, user-defined
Built-in sensors	motion, temperature, ambient light, pressure	motion, temperature, ambient light, magnetometer, pressure	motion, temperature	motion, temperature	n/a
Estimote Indoor Location	automapping	manual mapping	n/a	tracking Nearables	n/a
Additional tech	mesh networking, GPIO, RTC, RGB LED, 1Mb EEPROM, programmable NFC	mesh networking, GPIO, RTC, LED, 1Mb EEPROM, programmable NFC	programmable NFC	n/a	WiFi, HDMI, USB, 1GB eMMC storage
Devices in the Kit	4 beacons	3 beacons	3 beacons	10 stickers	3 mirrors

Appendix B

Definitions of Acronyms

Table B.1. Definitions of acronyms

Acronym	Meaning
BFO	Basic Formal Ontology
BIGML	Big Machine Learning
BLE	Bluetooth Low Energy
BPM	Business Process Management
BPMN	Business Process Model and Notation
CPN	Color Petri Net model
CR networks	Cognitive Radio Networks
DNS	Domain Name Service
DOG	Domain Ontology Graphs
ERL	Emergency Rescue Localization
ERP	Enterprise Resource Planning
GA	Genetic Algorithm
GEO	Geography
GPS	Global Positioning System
GSO	General Social Ontology
iBeacon	iBeacon is the name for technology standard of Apple, which provides the mobile application to attend for signals from beacons in the physical environment and respond accordingly (both iOS and Android)
indoorGML	Indoor Geography Markup Language
INS	Inertial Navigation System
IoT	Internet of Things
IPS	Indoor Positioning System
LBS	Location-based Service
LI	Location Intelligence
LMS	Lectin-magnetic Separation
MMP	Multiple Magnetometer Platform

Acronym	Meaning
MPC	Mobile Positioning Center
NLP	Natural Language Processing
OntoNav	Ontology Navigation
OWL	Web Ontology Language
QR Code	Quick Response Code
RDF	Resource Description Framework
RF	Radio Frequency
RFID	Radio-Frequency Identification
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
TBAO	Building Arabic Ontology system
TOTIS	Task-Oriented Tourist Information System
TX Power	Transmit Power
UOC	Upper Ontology of Culture
UTS	University of Technology Sydney
UUID	Universal Unique Identifier
WCL	Weighted Centroid Localization
WLAN	Wireless LAN

Appendix C
Definitions of Requirement Code in the Experiment

Table C.1. Definitions of requirement code (Estimote 2016)

Requirement Code	Description
EmmaLpt01	Emma's laptop 01
FLP_001	Code of finding lost properties route in the building in Test Case 1
FLP_002	Code of finding lost properties route in the building in Test Case 2
FLP_003	Code of finding lost properties route in the building in Test Case 3
FR_inBLD01	Code of finding route in the building in Test Case 1
FR_inBLD02	Code of finding route in the building in Test Case 2
FR_inBLD03	Code of finding route in the building in Test Case 3
LxiPad01	Lex's iPad 01
McWal01	Michael's wallet 01
REQ_FLP01	Code of requirement of finding lost properties route in the building in Test Case 1
REQ_FLP02	Code of requirement of finding lost properties route in the building in Test Case 2
REQ_FLP03	Code of requirement of finding lost properties route in the building in Test Case 3
REQ_FR_inBLD01	Code of requirement of finding route in the building in Test Case 1
REQ_FR_inBLD02	Code of requirement of finding route in the building in Test Case 2
REQ_FR_inBLD03	Code of requirement of finding route in the building in Test Case 3

Route_array	Route array is route for using to navigate for user inside building

Appendix D
Definitions of Node Name

Table D.1. Definitions of example nodes

Code	Description	Coordinate (x, y, z)	Status	Level
MN	Mobile Node	Following by current mobile position of calculation (x, y, z)	On	4
SC04001	Space coordinate in Level 4 on number 001	200, 510, 255	On	4
SC04002	Space coordinate in Level 4 on number 002	345, 483, 255	On	4
SC04003	Space coordinate in Level 4 on number 003	356, 337, 255	On	4
SC04004	Space coordinate in Level 4 on number 004	509, 353, 255	On	4
SC04005	Space coordinate in Level 4 on number 005	505, 418, 255	On	4
SC04006	Space coordinate in Level 4 on number 006	762, 443, 255	On	4
SC04007	Space coordinate in Level 4 on number 007	884, 539, 255	On	4
SC04008	Space coordinate in Level 4 on number 008	1000, 548, 255	On	4
SC04009	Space coordinate in Level 4 on number 009	1154, 569, 255	On	4
SC04010	Space coordinate in Level 4 on number 010	1192, 509, 255	On	4
SC04011	Space coordinate in Level 4 on number 011	1225, 577, 255	On	4
SC04012	Space coordinate in Level 4 on number 012	1214, 729, 255	On	4

Code	Description	Coordinate (x, y, z)	Status	Level
SC04013	Space coordinate in Level 4 on number 013	752, 525, 255	On	4
SC04014	Space coordinate in Level 4 on number 014	675, 520, 255	On	4
SC04015	Space coordinate in Level 4 on number 015	571, 518, 255	On	4
SC04016	Space coordinate in Level 4 on number 016	495, 534, 255	On	4
SC04017	Space coordinate in Level 4 on number 017	372, 571, 255	On	4
SC04018	Space coordinate in Level 4 on number 018	285, 610, 255	On	4
SC04019	Space coordinate in Level 4 on number 019	306, 656, 255	On	4
Room04101	Room number 11.04.101 in Building 11 on Level 4	168, 513, 255	On	4
Room04102	Room number 11.04.102 in Building 11 on Level 4	193, 471, 255	On	4
Room04103	Room number 11.04.103 in Building 11 on Level 4	324, 439, 255	On	4
Room04105	Room number 11.04.105 in Building 11 on Level 4	327, 351, 255	On	4
Room04200-201	Room number 11.04.200-201 in Building 11 on Level 4	656, 405, 255	On	4
Room04202	Room number 11.04.202 in Building 11 on Level 4	771, 417, 255	On	4
Room04203	Room number 11.04.203 in Building 11 on Level 4	863, 450, 255	On	4
Room04205	Room number 11.04.205 in Building 11 on Level 4	1011, 461, 255	On	4

Code	Description	Coordinate (x, y, z)	Status	Level
Room04300	Room number 11.04.300 in Building 11 on Level 4	1238, 506, 255	On	4
Room04301	Room number 11.04.301 in Building 11 on Level 4	1264, 635, 255	On	4
Room04400	Room number 11.04.400 in Building 11 on Level 4	971, 575, 255	On	4
Room04401	Room number 11.04.401 in Building 11 on Level 4	874, 568, 255	On	4
ToiUnisex04001	Unix Toilet RH (Right hand dismount) and Baby change number 001 in Building 11 on Level 4	597, 559, 255	On	4
ToiM04001	Male Toilet and Ambulant Male Toilet number 001 in Building 11 on Level 4	642, 616, 255	On	4
ToiF04001	Female Toilet and Ambulant Female Toilet number 001 in Building 11 on Level 4	635, 666, 255	On	4
LK04001	Elevators for going to different floors, this link number 001 in Building 11 Level 4	438, 574, 255	On	4
LK04002	Stairs for going to different floors, this link number 002 in Building 11 Level 4	496, 492, 255	On	4
LK04003	Escalators for going to different floors, this link number 003 in Building 11 Level 4	729, 479, 255	On	4

Code	Description	Coordinate (x, y, z)	Status	Level
LK04004	Corridor for going to Building 10, number 004 in Building 11 Level 4	315, 682, 255	On	4
LK04005	Corridor for going to Building 10, number 005 in Building 11 Level 4	1208, 757, 255	On	4
EX04001	Fire Exit number 001 in Building 11 Level 4	229, 556, 255	Off	4
EX04002	Fire Exit number 002 in Building 11 Level 4	553, 663, 255	Off	4
EX04003	Fire Exit number 003 in Building 11 Level 4	1186, 600, 255	Off	4
BLE04001	BLE devices number 001 on Level 4 in Building 11	263, 644, 255	On	4
BLE04002	BLE devices number 002 on Level 4 in Building 11	367, 488, 255	On	4
BLE04003	BLE devices number 003 on Level 4 in Building 11	414, 594, 255	On	4
BLE04004	BLE devices number 004 on Level 4 in Building 11	483, 445, 255	On	4
BLE04005	BLE devices number 005 on Level 4 in Building 11	601, 534, 255	On	4
BLE04006	BLE devices number 006 on Level 4 in Building 11	676, 437, 255	On	4
BLE04007	BLE devices number 007 on Level 4 in Building 11	744, 541, 255	On	4
BLE04008	BLE devices number 008 on Level 4 in Building 11	903, 467, 255	On	4
BLE04009	BLE devices number 009 on Level 4 in Building 11	1010, 570, 255	On	4

Code	Description	Coordinate (x, y, z)	Status	Level
BLE04010	BLE devices number 010 on Level 4 in Building 11	1030, 471, 255	On	4
BLE04011	BLE devices number 011 on Level 4 in Building 11	1230, 532, 255	On	4
BLE04012	BLE devices number 012 on Level 4 in Building 11	1245, 651, 255	On	4

Appendix E

Definitions of Space Inside Building

The map for ontology validation:

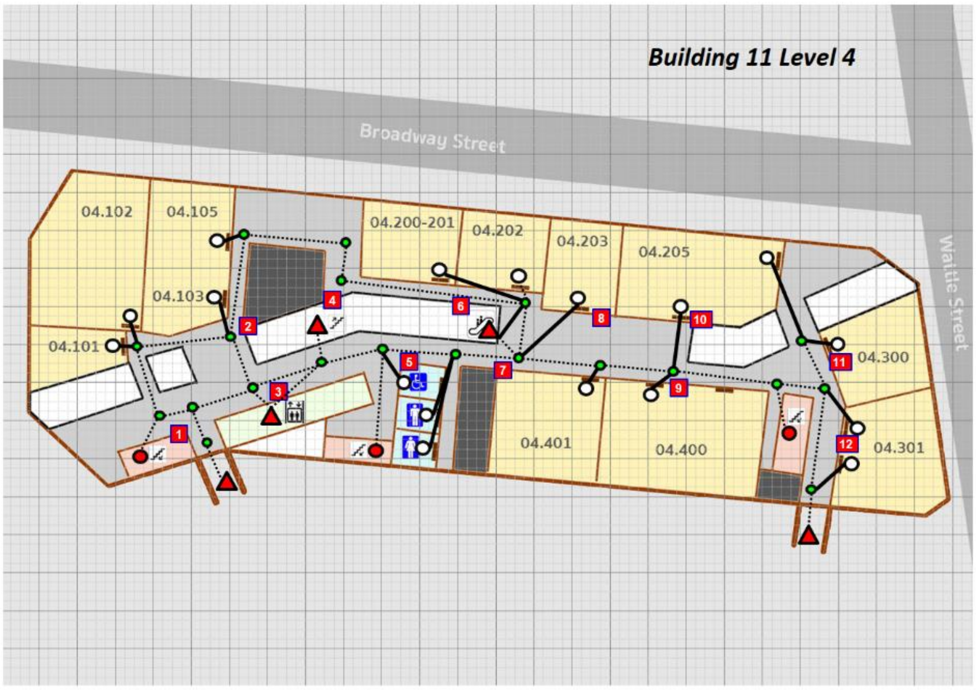

Figure E.1. Map of Level 4

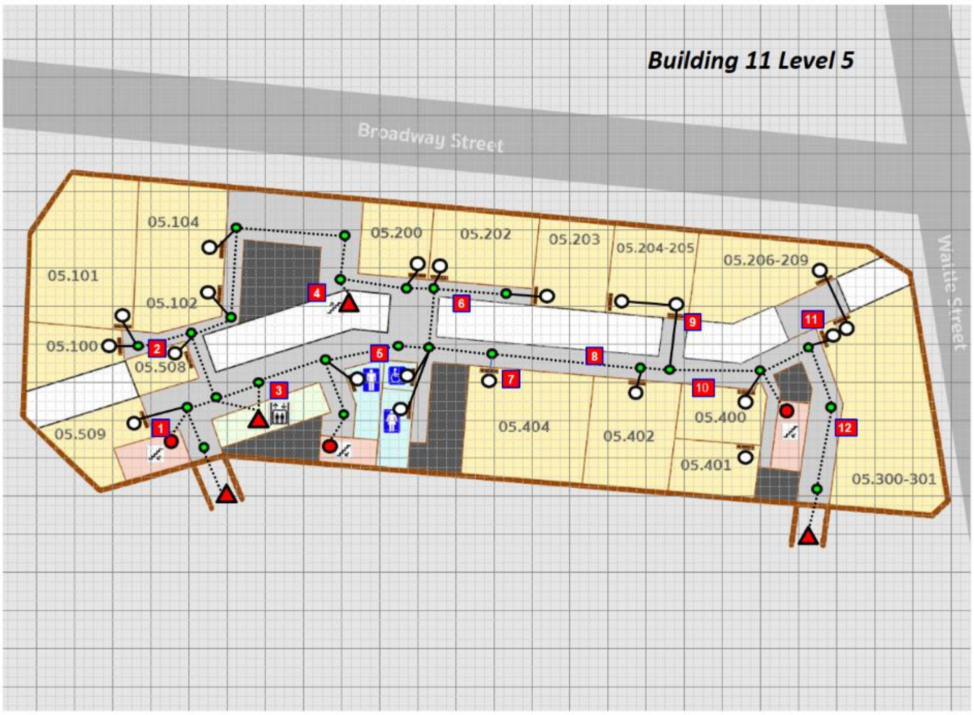

Figure E.2. Map of Level 5

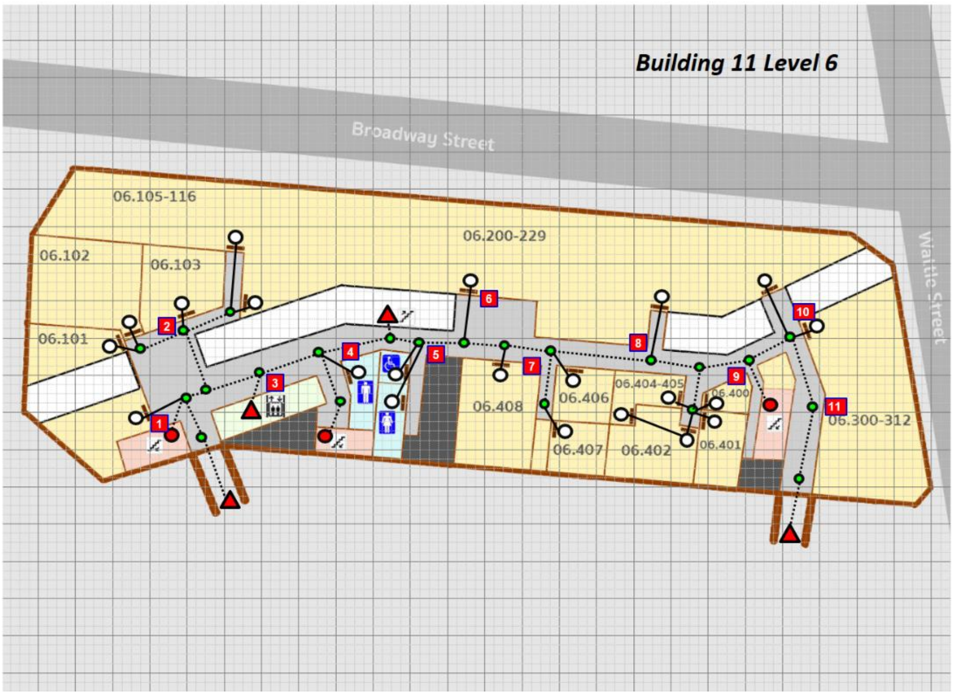

Figure E.3. Map of Level 6

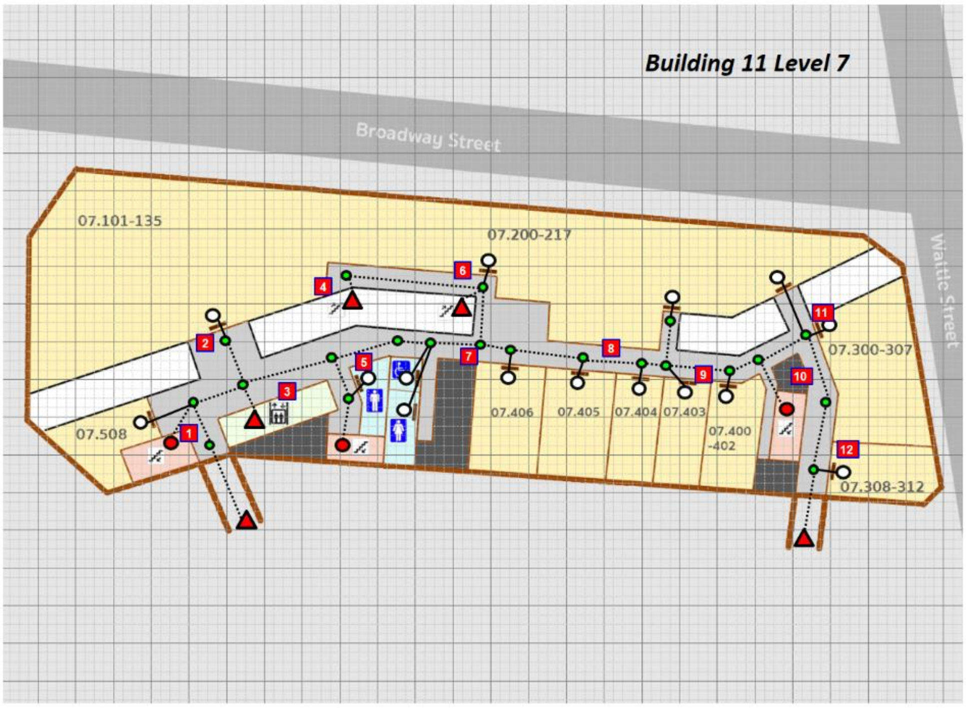

Figure E.4. Map of Level 7

Appendix F
Specification of LG Nexus 5

This research used LG Nexus 5. It has the specifications which allow it to be adapted for the experiments in this research. The detailed specifications are in Table F.1. In the experiment for this research the Android application "iBeacon & Eddystone Scanner" is used to collect data. The developer of this smartphone application is "Flurp laboratories", Germany.

Table F.1 Detail of LG Nexus 5 (GSMArena 2013)

Network	Technology	GSM / CDMA / HSPA / LTE
	2G bands	GSM 850 / 900 / 1800 / 1900 - all versions
		CDMA 800 / 1900 - North American version
	3G bands	HSDPA 800 / 850 / 1700 / 1900 / 2100 / 900 - North American version
		HSDPA 850 / 900 / 1700 / 1900 / 2100
	4G bands	LTE band 1(2100), 2(1900), 4(1700/2100), 5(850), 17(700), 19(800), 25(1900), 26(850), 41(2500) - North America
		LTE band 1(2100), 3(1800), 5(850), 7(2600), 8(900), 20(800)
	Speed	HSPA 42.2/5.76 Mbps, LTE Cat4 150/50 Mbps
	GPRS	Class 12
	EDGE	Class 12
Body	Dimensions	137.9 x 69.2 x 8.6 mm (5.43 x 2.72 x 0.34 in)
	Weight	130 g (4.59 oz)
	Build	Plastic body
	SIM	Micro-SIM
Display	Type	True HD IPS+ capacitive touchscreen, 16M colors
	Size	4.95 inches, 67.5 cm^2 (~70.8% screen-to-body ratio)
	Resolution	1080 x 1920 pixels, 16:9 ratio (~445 ppi density)
	Mulitouch	Yes

	Protection	Corning Gorilla Glass 3
Platform	OS	Android 5.0 (Lolipop), upgradable to 6.0 (Marshmallow)
	Chipset	Qualcomm MSM8974 Snapdragon 800
	CPU	Quad-core 2.3 GHz Krait 400
	GPU	Adreno 330
Memory	Card slot	No
	Internal	16/32 GB, 2 GB RAM
Camera	Primary	8 MP (f/2.4, 30mm, 1/3.2", 1.4 µm), autofocus, OIS, LED flash, check quality
	Features	Geo-tagging, touch focus, face/smile detection, panorama, HDR
	Video	1080p@30fps, check quality
	Secondary	1.3 MP (f/2.4, 1/6", 1.9 µm)
Sound	Alert types	Vibration; MP3, WAV ringtones
	Loudspeaker	Yes
	3.5mm jack	Yes
		- Active noise cancellation with dedicated mic
Comms	WLAN	Wi-Fi 802.11 a/b/g/n/ac, dual-band, Wi-Fi Direct, DLNA, hotspot
	Bluetooth	4.0, A2DP
	GPS	Yes, with A-GPS, GLONASS
	NFC	Yes
	Radio	No
	USB	microUSB 2.0 (SlimPort), USB Host
Features	Sensors	Accelerometer, gyro, proximity, compass, barometer
	Messaging	SMS (threaded view), MMS, Email, Push Mail, IM
	Browser	HTML5
		- Qi wireless charging
		- MP4/H.264 player
		- MP3/WAV/eAAC+ player
		- Photo/video editor

		- Document editor
		- Voice memo/dial/commands
Battery		Non-removable Li-Po 2300 mAh battery
	Stand-by	Up to 300 h (3G)
	Talk time	Up to 17 h (3G)
Misc	Colors	Black, White, Red
	SAR	0.92 W/kg (head) 1.23 W/kg (body)
	SAR EU	0.49 W/kg (head) 0.48 W/kg (body)
	Price	About 260 EUR
Tests		Basemark OS II: 1351 / Basemark OS II 2.0: 1016
	Performance	Basemark X: 11638
	Display	Contrast ratio: 967:1 (nominal) / 2.228:1 (sunlight)
	Camera	Photo / Video
	Loudspeaker	Voice 65dB / Noise 64dB / Ring 65dB
	Audio quality	Noise -93.3dB / Crosstalk -94.3dB
	Battery life	Endurance rating 38h