A Scalable Medical Devices Localization Service Modeling

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ABSTRACT

Medical applications of telemetry continue to evolve with the demand for real time networked medical data, and with minimum intrusion to the mobility of the patient. This paper presents several architectures for managing a scalable hospital's medical devices localization service and shows how these can be represented using the Unified Modeling Language (UML) model. It targets medical devices which are equipped with wireless technologies such as WiFi, Bluetooth Low Energy (BLE), etc. which can be incorporated into a networked telemetry system. The UML modeling demonstrates a scalable medical devices localization service for a hospital which can make use of client-server and cloud based architectures. The resulting model is a step towards a practical implementation of the service in tackling several problems which can arise due to the misplacement and improper sharing of medical devices in a healthcare scenario such as hospitals.

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

1. INTRODUCTION

Bluetooth Low Energy (BLE) forms the part of Bluetooth V4.0 specification that has been ratified by the Bluetooth SIG since June 2010. Applications and products which make use of this technology have seen a significant explosion such as health, fitness and location awareness. By incorporating BLE to mobile devices running applications, it is possible to provide gateway connectivity to the internet.

Today many enterprises and startups are building sophisticated wireless medical devices with complex companion software and mobile applications that rely on Bluetooth connectivity. Short-range Bluetooth connectivity between the medical device and the smartphone allows data transfers via the Wi-Fi and cellular antennas to integrate the on-device patient data with clinical systems and cloud-based architectures.

The BLE technology can be used for an additional purpose than its original intended functionality - the communication with the health care applications and infrastructure. The BLE can be used to track medical devices which could cause disease transmission due to improper sharing. Medical devices such as a blood glucose monitoring devices are Bluetooth enabled. As evidenced in the case of acute hepatitis B infection which occurred in a long-term care home (LTCH) in Toronto, Canada, the Hepatitis B Virus (HBV) outbreak was associated with shared blood glucose monitoring equipment. To prevent hepatitis B transmission, it was recommended that a glucometer and finger-stick device be assigned to each diabetic resident requiring blood glucose monitoring in addition to following routine infection control practices [1]. Similar incidents were also investigated in psychiatric long-term care facility [2].

Medical devices which are assigned to be dedicated to specific patients should be tracked to avoid misplacement. To reduce the risks of infections associated with the sharing of medical devices due to misplacements, we implemented a pilot project in our previous work which tracks those BLE equipped medical devices. The experimental results show how this Bluetooth Low energy technology which is currently available in many medical devices can be used to properly track these medical devices in a long term care home scenario [3].

This paper addresses the first step, UML based service modeling of a scalable scenario of the localization application, towards implementing in a bigger area such as a multi-story healthcare building. Nowadays, service-oriented architectures are becoming gradually more important. There is a vast diversity of implementation and support platforms for this kind of architecture, such as client-server and cloud. This increases the complexity of the development process of service-based systems. With the aim of facilitating the development of localization service solutions, we propose a specification of the architecture for this application.

Wireless medical telemetry is generally used to monitor a patient's vital signs such as pulse, and respiration. These devices have the advantage of allowing patient movement without restricting patients to a bedside monitor with a hard-wired connection.

2. BACKGROUND

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

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

2.1 Bluetooth LE in Medical Devices

In 2003, only two years after Bluetooth wireless technology was officially released to the world, the U.S. Food and Drug Administration (FDA) approved a Bluetooth enabled medical device for the first time. It was a Serial Port Adapter for emergency room equipment, designed for applications like wireless printing of electrocardiograms or transmitting medical images over the air.

As manufacturers of different medical devices are causing interoperability issues, the Bluetooth Special Interest Group (SIG) formed the Medical Working Group (MEDWG). As a result there has been a seamless integration of medical devices in health care applications and infrastructure.

Incorporation of wireless technology in medical devices can have many benefits, including increasing patient mobility by eliminating wires that tether a patient to a medical bed, providing health care professionals the ability to remotely program devices, and providing the ability of physicians to remotely access and monitor patient data regardless of the location of the patient or physician (hospital, home, office, etc…). These benefits can greatly impact patient outcomes by allowing physicians access to real-time data on patients without the physician physically being in the hospital and allowing real-time adjustment of patient treatment. Remote monitoring can also help special populations such as seniors through home monitoring of chronic diseases so that changes can be detected earlier before more serious consequences occur [5].

Radio frequency (RF) wireless medical devices perform at least one function that utilizes wireless RF communication such as Wi-Fi, Bluetooth, and cellular/mobile phone to support health care delivery. Examples of functions that can utilize wireless technology include controlling and programming a medical device, monitoring patients remotely, or transferring patient data from the medical device to another platform such as a cell phone. As RF wireless technology continues to evolve, this technology will increasingly be incorporated into the design of medical devices.

2.2 Bluetooth LE Beacons

A BLE beacon is a wireless device that periodically broadcasts a Bluetooth Low Energy advertising packet that can be received by a smartphone and used to determine the position with respect to the beacon itself. This provides "context-aware" information to the mobile user, opening up the possibility to connect the online (virtual) world with the offline (real) physical world.

BLE beacons werefirst introduced by Apple’s iBeacon followed by Google’s Eddystone. Those BLE enabled beacons transmit a signal up to a certain distance, ranging from 15cm (~6 in) to 70m (~230 ft). Beacons provide a virtual region, when we identify with a specific region of the beacon then we can say that we are within that region. A Beacon broadcasts a Bluetooth signal which contains unique identity information frequently, so the coverage area will be filled with beacon signals; this area is called Beacon Region. Beacons have been attractive to retailers for implementing location based services (LBS) as they have a long battery life and low cost of maintenance.

This work is based on Estimote beacons [6] which provide developers with a ready-made Bluetooth LE device that can plug into Estimote's SDK and give Apps hyperlocal awareness – letting them detect nearby devices and provide contextual information about the world around them instantly.

3. SCALABLE BLUETOOTH LOW ENERGY LOCALIZATION FOR HEALTHCARE

In our previous works [3], we implemented medical devices localization over a small area as a proof of concept using an Android application. Developing a scalable medical devices localization architecture should be considered that will be able to support health care in multi-story buildings.

This section develops a scalable medical devices localization system based on BLE signals for medical devices with BLE. Identification of the rooms also uses BLE signals from the Estimote beacons. BLE or Beacon is a future trend. According to Bluetooth SIG, "by 2018 more than 90 percent of Bluetooth enabled smartphones will support Bluetooth Smart". In general, other wireless technologies such as WiFi can be also exploited to perform the localization.

The main reasons for using the Beacon technology are the following: low power consumption, 24/7 for over a year with a button cell battery; high supported range; cross-platform operation, and support wide range of devices. BLE is supported by different platforms including Android, iOS, and Windows and more. In addition, according to Bluetooth SIG, by 2018 more than 90 percent of Bluetooth enabled smartphones will support Bluetooth Smart [2].

Localization techniques can be employed. Although there is no specific support for positioning service in Bluetooth technology yet, the predominant technology used are signal strength measurement, link quality and bit error rate which rely on the services of the Host Controller Interface**.** Thus the Received Signal Strength Indicator (RSSI) value of the Bluetooth signal is used to get a correlation in the distance between sender and receiver in a network. RSSI value fingerprinting using Bluetooth Low Energy signals can be used for localization similar to the work in [7].

3.1 TECHNOLOGICAL ARCHITECTURE

This subsection discusses various technological architectures under consideration for scalable medical devices localization. These are the client-server architecture and cloud-based architectures.

3.1.1 Client-Server Architecture

The client-server architecture can be implemented using an iterative server which communicates with the client application. The client App can be developed to be able to connect to the server via a TCP socket. When the App is started it performs the following functions: it requests the user of the App to turn the BTLE function ON if it was OFF, it scans for BTLE devices, and scans for nearby Estimote beacons.

The server on the other hand accepts several incoming connections from different clients. It communicates with a database stored in mapping tables. Once it accepts a location request of a medical device under query, the server uses the Estimote's id to map the room and look for the correctly assigned medical device to that particular room. It replies with this information and the client displays the assignment to the user.

3.1.2 Estimote Cloud Architecture

A second type of architecture can be implemented using a cloud computing. The cloud provides a software service which will mainly be used for managing the BLE based beacons which are installed in the healthcare building. Considering the fact that a multi-story building will require installation of a few beacons in each of the rooms, the total number of beacons inside the building will be considerable.

The Estimote provides a SaaS cloud service to manage beacons deployed inside a building. The deployment in each of the rooms can be done using their App to scan while walking around the room where the App suggests the number and placement of the beacons. Once this phase is completed, we can use an application token to access our beacons for localization. After the beacons are installed, Estimote Cloud exposes a public RESTful API that can access the beacon fleet data in a programmatic, machine-friendly way. The API can be used to fetch data about the beacons; perform Estimote analytics; use fleet management API and integrate Estimote Cloud with an independent backend. Using the Estimote cloud architecture, the localization system can be deployed across hundreds of locations using SaaS subscription which has the above mentioned features, applications, and APIs.

3.2 FUNCTIONAL ARCHITECTURE: UML MODELLING

This section focuses on service oriented architectural modelling using UML. The UML diagramsin this section are a partial graphical representation (view) of the model of the medical devices localization system under design for scalability based on the previously demonstrated proof of implementation.

3.2.1 USECASE DIAGRAM

Use Case diagrams [8] are usually referred to as behavior diagrams used to describe a set of actions (use cases) that some system or systems (subject) should or can perform in collaboration with one or more external users of the system (actors). Each use case should provide some observable and valuable result to the actors or other stakeholders of the system.

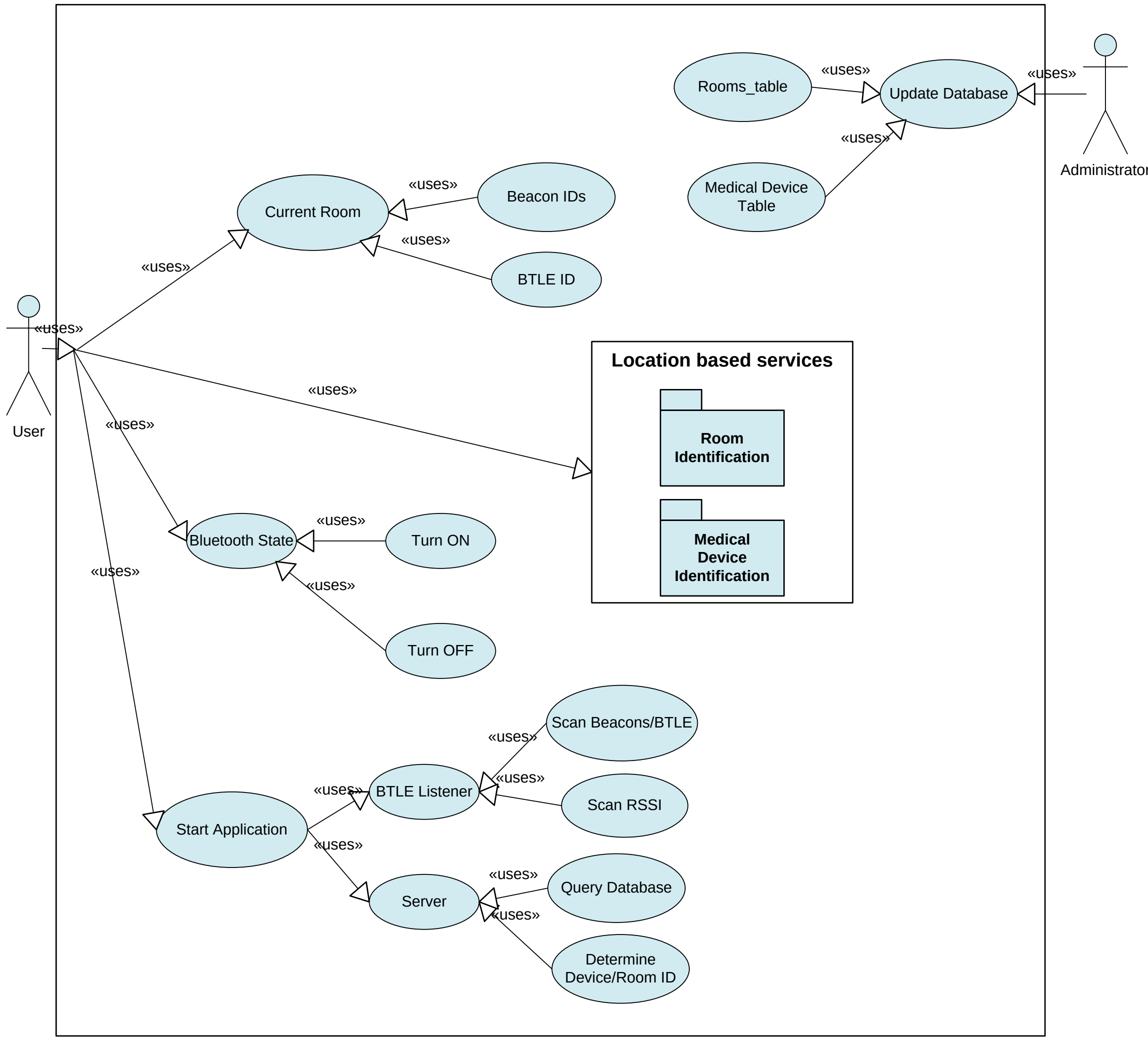

Figure 1: Use Case Diagram

3.2.2 SEQUENCE DIAGRAM

Sequence diagram describes an interaction by focusing on the sequence of messages that are exchanged along with their corresponding occurrence specifications on the lifelines.

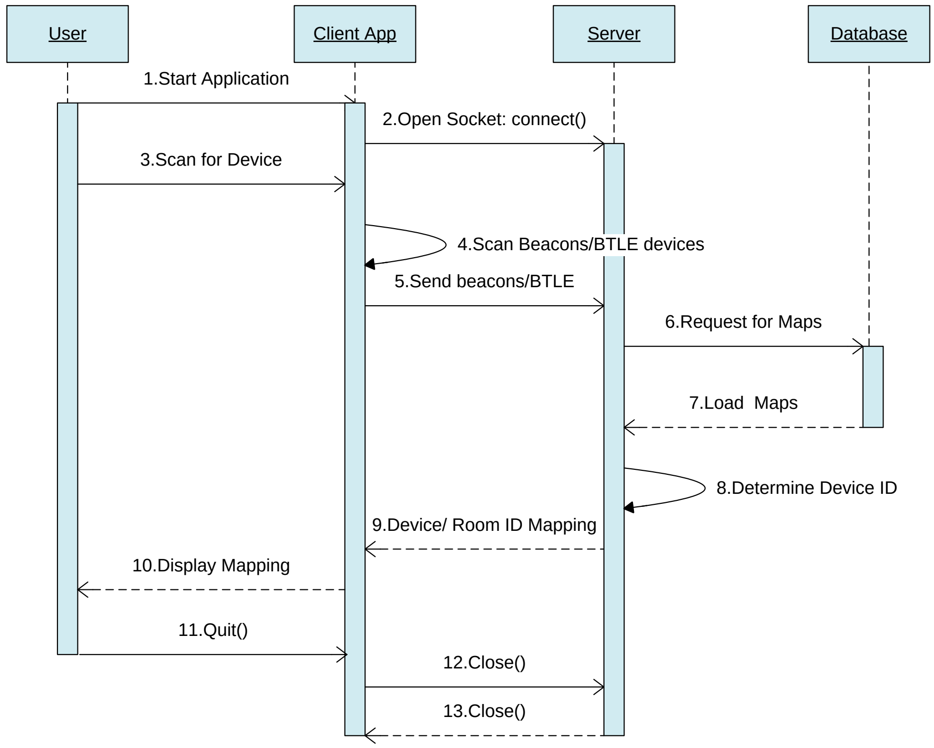

Figure 2: Sequence Diagram: Client

1. A user starts the localization App installed on a mobile device. If the device is not capable of supporting BLE, it notifies the user. If the device supports BLE but it is not turned ON, it notifies the user to turn it ON.
2. The client App opens a socket connection either via TCP or UDP to the server.
3. User presses the Scan devices button on the client application and the App scans BLE devices.
4. The client App scans for Estimote beacons and BTLE devices which are reachable.
5. The client sends the scan results (both the BLE devices and beacons) to the server.
6. Server requests for the maps between devices and rooms to the database.
7. The database loads maps to the server after performing the right query.
8. Using the localization algorithm, the server determines the device ID associated to a room.
9. The sever sends the Device-to-Room identity mapping to the client App.
10. The client displays to the used the mapping.
11. The user quits the application.
12. Client closes the socket to the server.
13. The server closes the socket to the client application.

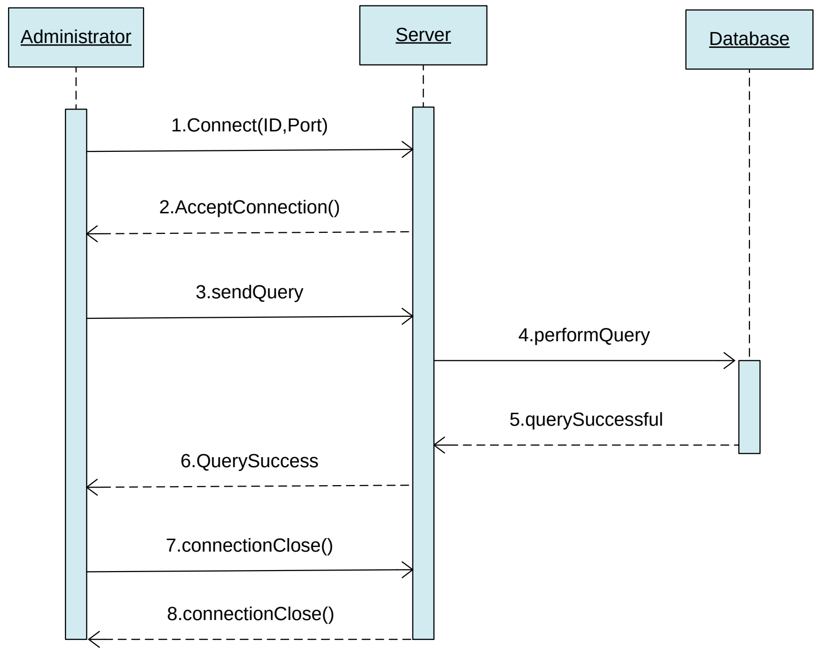

Figure 3: Sequence Diagram: Administrator

1. The administrator sends a connection request to the server via its specified ID and port.
2. The server accepts the connection request from the administrator after successful authentication.
3. The administrator sends a query to the server.
4. The server relays the query request from the administrator to the server.
5. The database executes the query. After a successful query execution, the database sends a query success message to the server.
6. The server notifies the administrator the success of the query
7. The administrator sends a connection close message to the server.
8. The server replies with a connection close message to the administrator after closing the connection.

3.2.3 CLASS DIAGRAM

Shows structure of the designed system, subsystem or component as related classes and interfaces, with their features, constraints and relationships/associations, generalizations, dependencies, and more.

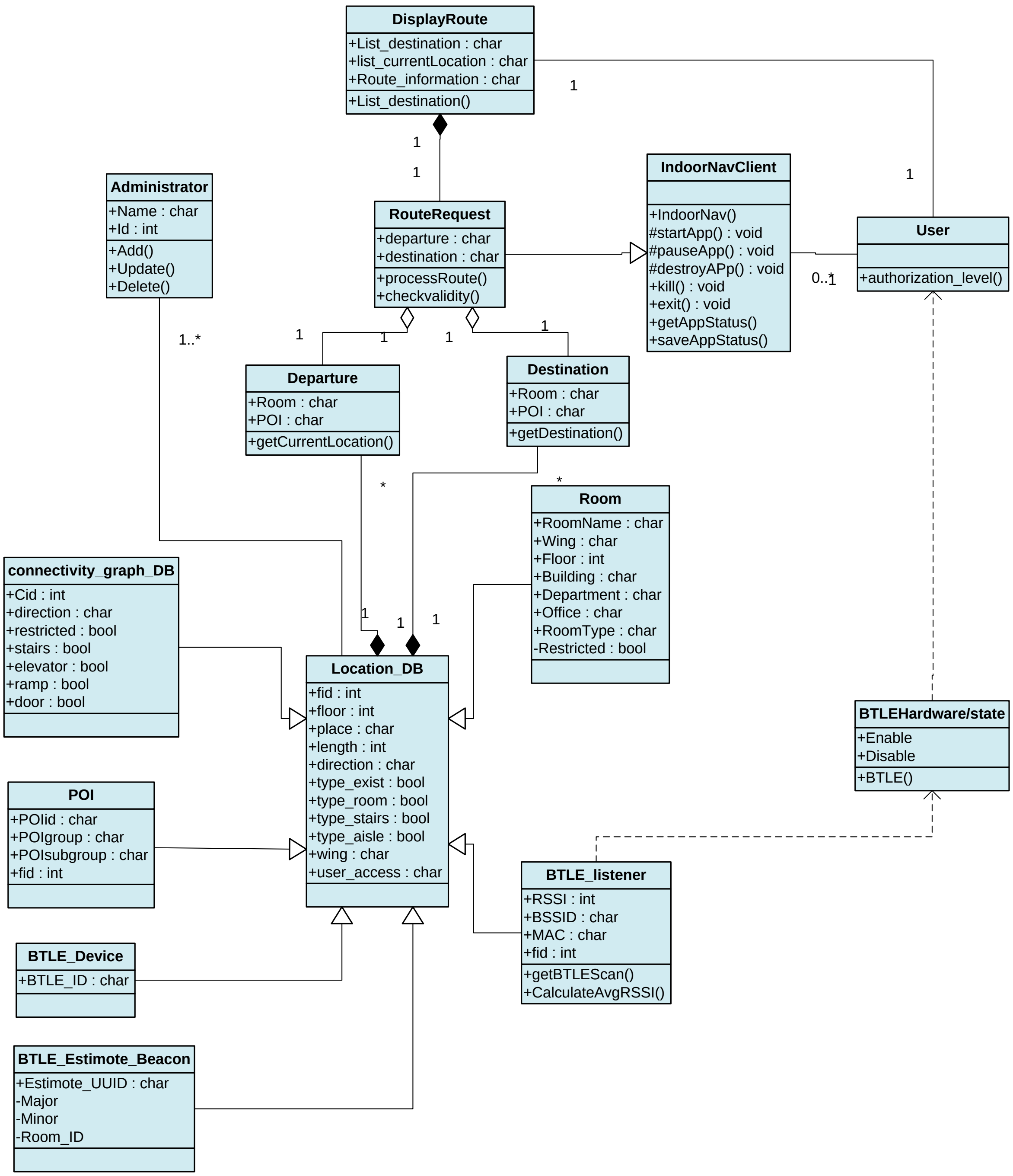

Figure 4: Class Diagram of the Structure of the System

The domain model diagram is an instance level diagram which shows instance specifications and interfaces (objects), slots with value specifications and links (instances of associations). The class diagram specified in Figure 4, can be extended to implementation class diagram which includes indoor navigation capability besides the localization of medical devices. The classes such as Departure, Destination, IndoorNavClient, RouteRequest and DisplayRoute implement the part of the application which supports indoor navigation capability. The other classes implement the BTLE localization, Bluetooth device hardware functionality, Points of interest (POI) and database connectivity.

4. CONCLUSIONS AND FUTURE WORK

This work highlights scalable modeling of medical devices localization. We develop several architectures for managing location services for BLE devices and demonstrate how UML modeling can be used to capture these for comparison. It has been demonstrated that the use of Estimote beacons and medical devices which are equipped with BLE devices can be used to implement a localization system. Previous experimental work covered a small area and targeted a single floor building. The UML modeling demonstrated in this work is a step into the implementation of a scalable localization system which covers an entire multi floor building. Future work will investigate expansion of the previous pilot implementation to scale into larger area and multi-story healthcare building to perform medical devices localization.

5. REFERENCES

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