Master Thesis

Bluetooth Low Energy Supported Indoor Location

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***Abstract*—Abstract**

I. Introduction

Indoor positioning systems have greatly evolved in the past few years due to the great success of its counter-part, the global positioning system (GPS), in outdoor environments but failure to reproduce the same results in indoor environments. Since GPS is an outdoor position systems and is based on a network of satelite, when the required scenario for position tracking is inside a building, new constraints are presented onto the process such as the attenuation and reflection of eletromagnetic waves upon collision with building walls and obstacles [5]. As such there was a need to find reliable indoor systems that by nature would already be able to heavily reduce the impact of some of the mentioned constraints.

In order to understand indoor position there is a need to understand the full scope of variables that come to surface when moving from outdoor to indoor. When developing an indoor system there is a need to make sure that it can tackle the chalenges such as small space dimension which reforce the need for higher precision, a higher probability of non existent line of sight, influence of obstacles such as walls, furniture, moveable objects such as doors and human beings[3]. All of the previously mentioned affect the way electromagnetic waves propagate in an indoor environment leading to problems related to severe multipath and reflection on existent surfaces [2]. Besides propagation challenges, there are energy consumption, accuracy and deployment costs that play a critical role in deciding the viability of a proposed indoor location technique.

With the evolution of mobile devices there has been a sizeable number of different technologies that can possibly be used in indoor locationing [2], [4], [5] such as GPS-based technologies, using high sensitivity antenas to overcome GPS's indoor issues, RFID , Wireless LAN and Bluetooth among others, allowing even for hibrid systems which make use of more than one of the technologies mentioned above.

Another important aspect besides the chosen technology is the location detection technique which are widely varied in terms of accuracy and complexity. The simplest available category would be proximity detection which has Cell of Origin (CoO) as its most famous technique, allowing for room-based detection by assuming that the mobile target is at the cell with the strongest receiving power. This technique is widely used by system using RFID, Bluetooth and Infrared. The next category would be triangulation which uses the geometric properties of the triangle to obtain a position. The method utilized to obtain the values used in the position's calculation can be angle-based, which have implementation costs are their worst limitation; time-based, using Time-of-flight (ToF) or Round Trip Time (RTT) to obtain measures of distance from beacons; signal property based, using received signal strength indicator (RSSI) as a metric, altough it's only possible of using this metric with radio signals; dead reckoning, which calculates the actual position utilizing the last determined position and incrementing based on estimate of the device's speed.

When taking into consideration every possible technology and existant algorithm that are capable of being applied on indoor location, we find ourselves with a wide variaty of solutions. This high number of variations has led to an increase on the number of existing surveys which attemp to gather make a collection of what has been achieved in the field. Looking at this opportunity I saw the possibility of attempting to create a generic platform capable of being utilized by any existing indoor location system. In order to implement and test the solution there was a need to decide on which technology to be used and as such I opted by the bluetooth low energy.

In this paper is structured in a way that in II an overview of Bluetooth low energy (BLE) and existent projects and their associated architecture are presented while shedding light on the benefits and limitations of the chosen technologies. Section III overviews the architecture of the proposed generic system, while section **??** presents the finalized system by analyzing the utilized technologies. Section V analyzes the different aspects of the presented solution in terms of energetic efficiency, accuracy and response timings, finalizing in section VI by overviewing what could be carried out in order to further develop the existing work and by concluding the paper.

II. Related Word

Indoor location systems is a field that has only been researched for a few couple of years but from the very begining until now there has been a very large amount of changes. In order to understand the progresses made there is a need to dwell into the systems which functioned as bases for progress.

In 1992 the Active Badge system [11] was presented as an infrared solution which was capable of provided room-based position tracking, due to infrared signals being unable to to travel through walls, and whose's information was then stored in a centralized location database [12]. This system imposed users to carry with them an ID card equiped with an IR LED which emitted a signal each fifteen seconds. The long signal frequency was due to the chance of collision of signals from multiple users in the same location while also having in mind energy cost which need to be kept as low as possible. One of the downsides was the decrease in accuracy as the user's location is only known at best to a 15-second window. The user's location was obtained through the implementation of a network of sensors which act as receivers and then forward the obtained information to the master station which would take care of polling the sensors, processing data and then making it available to users. One of the biggest issues that were raised with this system was the privacy concerns raised by the clients due to its object tracking nature.

At the beggining of the twentieth century, two remarkable projects were presented, Bat system [13] and RADAR[16]. The first one, Bat Ultrasonic Location System, was a system capable of tracking various objects, each with a small wireless device called bat [14], [15]. A bat consisted of a radio transmitter, each had a unique identifier and was ment to be carried by personnel or attached to objects. In order to locate a bat, there was a base station which periodically transmitted a signal with a single identifier which caused the corresponding bat to emmit an ultrasound pulse. The same pulse was then captured by an existing grid of receivers, which were placed on the ceiling of the areas to be covered, which recorded the time of arrival of the ultrasound. Since the receivers are also capable of receiving the initial base station's message they are capable of computing the ultrasound's time of flight, which is then forwarded to the base station for further computation. Since the speed of sound in the air is known, the system was capable of converting the time of flight of the ultrasound and convert it into bat-receiver distance. In order to obtain the bat's location, if at least three receivers had caught the bat's signal, it was possible to utilize multilateration to obtain its 3D position. Due to the nature of the system, only one bat can be localised at a time, as such the process was diveded into time slots which garanteed that each time slot had enough time to obtain a bat's position and for its emitted signals to die out.

The Radar system is a RF-based system to locate and track users inside buildings. The system is devided into two phases, an offline phase used for data collection and a real-time phase where a location is obtained. For data collection the mobile application and the base stations are synchronized, in order to be able to obtain time stamps and then the mobile user periodically emits UDP packets to the base stations (BS) . Each BS records the RF signal strength measurement together with the time stamp. This information gathering happens in both offline and real-time phases. During only the offline phase, while the mobile user emits packets, it also indicates his position on the map through (x,y) coordinates together with the timestamp. The real-time phase utilises the real-time user's packet associated RF signal strength, which is obtained at each bs and later on forwarded to the central computer where the computation is made, and examinates it in order to find the best fit for the current transmitter position.

The last remarkable project, Cricket, was introduced in 2005 which managed to tackled some of the problems presented in the last [19]. Each node in the cricket system is composed of a RF transceiver and hardware capable of generating and receiving ultrasonic signals. There are two types of nodes, beacons, which are fixed reference points and are attached to the ceiling or walls of the building, and listeners which are attached to the objects that need to be tracked. Each beacon periodically transmits a RF signal message containing beacon specific information, such as unique ID and beacon position. Whenever a RF signal is transmitted, an ultrasonic pulse is also emitted which enables listeners to measure their distance to the beacons by using the time difference of arrival times of the RF and ultrasonic signals. Each listener utilizes the RF signal's beacon information alongside the obtain distances to beacons to compute their space position and orientation. Crickets Architecture allowed to solve the user pribacy, decentralized and ease of deployment issues there were present in the remaining projects [18].

TODO recent stuff

Bluetooth is a wireless technology that was created in 1994 with the objective of replacing cables connecting fixed or portable devices. At this point in time Bluetooth Special Interest Group is in charge of developing and managing this technology characterized by its robustness, low energy consuption and low cost. The Bluetooth Low Energy protocol was introduced with the Bluetooth Core Specification version 4 (also called Bluetooth Smart) circa 2010 alongside two other protocols. Out of the three, BLE standed out for its lower power consuption, lower complexity and lower cost, while allowing for device discovery, connection establishment and connection mechanisms.

The BLE radio operates at the 2.4GHz band and employs a frequency hopping transceiver to combat interference and fading. It also employs two multiple access schemes: FDMA used to separate the 40 available physical channels, 37 of them are used as data channels and the remaining as advertising channels and TDMA in a polling scheme that is used when one device transmits a packet at a predetermined time and a corresponding device responds with a packet after a predetermined interval.

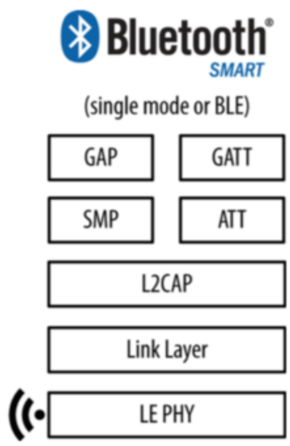

Fig. 1: Bluetooth low energy architecture

When looking at the BLE's architecture , which can be seen at 1, the Generic Access Profile (GAP) is one of the most relevant since it's responsible for working in conjunction with Generic Attribute (GATT) to define the base funcionality of BLE devices. The services that are made available by the

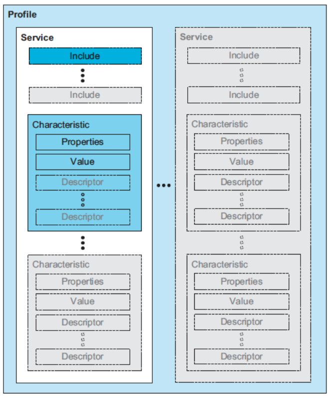

Fig. 2: Gatt-based profile hierarchy

GAP are: BLE device discovery, connection modes, security, authentication, association models and service discovery. In addiction to this, it also defines four different roles to describe a device, allowing for the controllers to be optimized in funtion of the device's desired roles: Broadcaster, role optimized for transmitter-only applications; Observer, role optimized for receiver-only applications and it's complementary to the broadcaster role; Peripheral, role optimized for devices that only want to suppot a single connection, allowing for a much less complex controller due to the fact that it only needs to support the slave role and not the master one; Central, role supports multiple connections and funtions as the initiator for all of them. These connection are all made with Peripheral devices and its controller must support the master role in a connection and allow for more complex funtions, in comparison to the remaining roles.

Another important component is the Attribute Protocol (ATT) Protocol which is responsible for implementing the Peer-to-peer(P2P) protocol between an attribute server and client. This communication happens in a dedicated fixed channel and a server can send through it responses, notifications and indications, while the client can send requests, commands and confirmations. The ATT allows the clients to read and write values of attributes on a peer device acting as a server.

The last component is the Generic Attribute (GATT) Profile which is responsible for creating a framework for the ATT, in which it's represented the funcionalities of an ATT server. This profile describes the hierarchy of services, characteristics and attributes existent in the server and provides an interface for discovering, reading, writing and indicating service characteristics and profiles.

Bluetooth low energy devices utilize profiles which define the required functionalities of the device. It also defines application behaviour and data formats and as such when two devices comply with all the requirements of a Bluetooth profile, application interoperability is achieved. Each Bluetooth profiles describes its requirements necessary for devices to create a connection, to find available services and connection information required for making application level connections.

The base profile that any Bluetooth system needs to include is the GAP. From this point, any additional profile implemented will be a superset of GAP, where GATT is included and specifies the profile hierarchy, or the structure in which profile data is exchanged. Figure 2 shows the hierarchy in a Gatt-based profile, with the profile being the top level and services and characteristics below. A profile is composed by one or more services. A service is a collection of data and associated behaviors to accomplish a particular function or feature of a device or portions of a device. A service is composed of characteristics and/or references to other services. A Characteristic is a value that is used in a service that has properties and configuration information that descrive how the value should be accessed as well as information on how to display the value. A characteristic is defined by its declaration, its properties, its value and may also be defined by its descriptor, which describes the value or permit configuration of the server relative to the value.

When looking at what's possible to achieve using the BLE technology there is the example of Apple's creation iBeacon [7] which was presented in 2013 with the porpuse of implementing proximity sensing systems. The device is capable of playing on the broadcaster role and as such its objective is to send nearby compatible receivers certain information. Some examples of application are to track customers or trigger location-based actions on devices such as push notifications or checking in on social media, with pratical cases such as the usage of iBeacons by McDonalds to offer special offers to their customers in their fast-food stores. An indoor location system utilizing this technology was presented by Jingjing Yang et al [**?**], where these devices were used to indicate a pacient of his whereabouts through the proximity sensing proprieties and this information was later transfered over to a server in order to give clients a variaty of different services, from pacient counting, to nearby department's information and offer indoor guidance to the nearest available bed.

When utilizing BLE for indoor location the usual metric used to calculate distances is the RSSI. This metric withint the context of bluetooth brings to surface several issues such as the fact that RSSI as a metric is very accurate only when the target is within a meter of the beacon, since the value decreases as the inverse of the square of the distance to the beacon . As such when developing solutions for indoor location that require system with high accuracy capable of tracking moving objects, the usage of RSSI can't be utilized without further work. Faragher et al [8] tackled one of the techniques used to improve BLE system's accuracy, fingerprinting, by verifying the effects caused by the device deployment density within the required location. This experiment also puts into evidence one of the downsides of the bluetooth technology being that its scalability is low, besides requiring higher density in order to increase accuracy, due to their low range any need to increase coverage leads to increased costs.

Zonith [10] introduced a bluetooth based location system with the objective of tracking the position of workers in dangerous environments. Any device registered in the zonith implemented network would be continuously tracked and accounted for in each of the system's functionalities such as, sounding an alarm whenever a lone worker doesn't move or responde within a time interval (Lone worker protection) or providing a quick an precise location of any worker that has

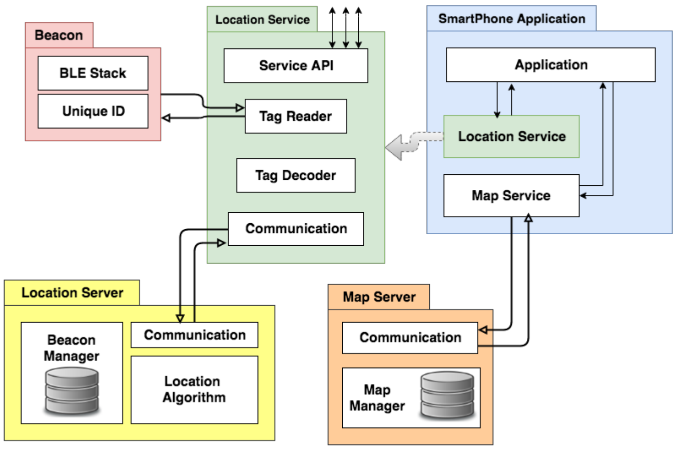

Fig. 3: Generic System's Architecture

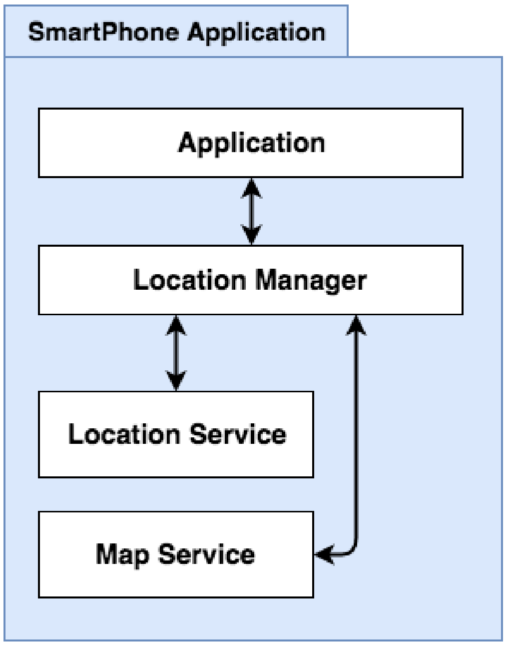

Fig. 4: Adjustments to the application required for multiple indoor location systems

requested for help. This system's installation requires planing of the best locations to place the beacons and number required of beacons in order to be able to provide enough courage and make sure the system provides the required quality.

III. Architecture

The solution presented in this paper was made with the objective of creating a generic indoor location system capable of being implemented using any existant indoor system created. The generic system's architecture is presented in figure 3 and it's divided in 4 parts: beacon, location server, map server and smartphone application.

The beacon represents any form of hardware responsible for providing fixed reference points which are fundamental in calculating a user's position. A beacon needs to be be composed of two structural blocks: The Unique ID, which stores any information crucial to identifying a beacon, and the Hardware specific software component, which contains all the necessary software to accomplish communication with a certain technology.

The location server is divided in three: the Communication block, which is responsible for creating, managing and terminating a connection with the mobile application; the location algorithm, architectural block responsible for applying a certain location algorithm to the data received from the application in conjuntion with the server's device information in order to obtain a concrete location; and the beacon manager which functions as a database where all the beacon associated with the server are stored.

The map server represents the architectural block responsible for providing the maps associated to the location of user obtained through the location service on the application. As such it requires a communication block which needs to be capable of communication with the map service of the application and takes care of creating, managing and terminating connections, and a map manager which stores the existing maps that are to be transfered to the application.

The smartphone application is divided into three functional blocks: core application, location service and map service. The core application contains the core functionality of the application and is in charge of communicating with the existing services. Communication with the location service allows for requesting the user's location which is then forwarded to the map service, in order to obtain the associated map. The location service is composed by four blocks: the API component through which it communicates with the core of the application; the tag reader which is the functional block responsible for reading a certain type of tags (beacons) and as such its structure will depend on the type of beacon utilized by the service; the tag decoder, functional block responsible of utilizing the information obtained through the tag reader and process it in order to be forwarded to communication block; the communication block which takes care of the creating, managing and terminating connections with a location server.

It might be relevant to analyze some types of indoor location system that could diverge from this architecture, such as camera or Quick Response (QR) code-based systems. These systems would still follow the proposed architecture except for the beacon component which would not be existant and the location service's tag reader block wouldn't need any sort of communication since it would be responsible of utilizing the camera to capture either a fotograph or reading a QR core.

Although figure 3 is representative of a system utilizing a single type of technology, the presented solution is scalable, allowing for insertion of additional indoor location systems onto a single architecture. The changes required for implementing such a scenario would be to add one extra layer of complexity on the android application as present on figure 4. In this new architecture, the application's core would only communicate with the location manager and the latter would now be responsible of managing through all of the location services and request execution of whichever service would be more suited or available. The location manager would also be

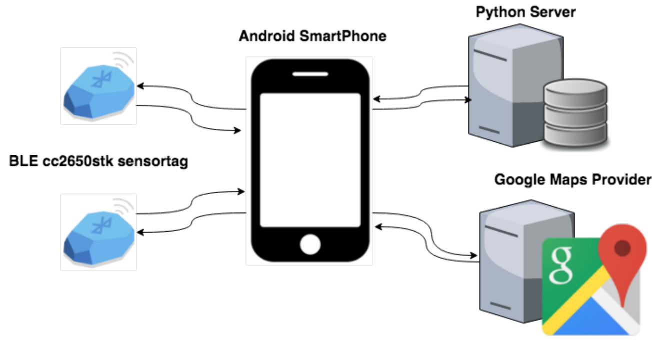

Fig. 5: System's Architecture

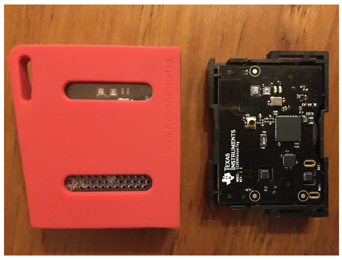

Fig. 6: TI cc2650stk sensortag

required to manage through the existant map services, which may or may not be in same number as the existant location services, and make sure that the data obtained from a certain location service is forwarded to the correct map service which must capable of processing it.

IV. Implementation

The implementation presented in this paper was created by utilizing the generic indoor location system presented in section III and applying it with bluetooth low energy. The system's architecture is presented in figure 5 and is divided three parts: the bluetooth low energy device, in section IV-A a description of the used technologies and the changes made are present;the server, whose funcionalities and stored information are described in section IV-B; and the smartphone application, whose process is described in section IV-C alongside figures that show the functional prototype. For each of these parts an explanation will be given, containing a description of each of its components specific to the presented system alongside the requirements for each to work.

A. BLE beacon

The beacons that were utilized are Texas Instruments CC2650STK devices which can be visualized in figure 6. Alongside the device, which comes with a pre-installed bluetooth low energy program capable of giving information on each of its ten sensors through its predefined profiles, there is a texas smartphone application that can connect to a single device and read from its sensors. By using the texas Code Composer Studio (CSS), the pre-defined ble profile existant on the device could be altered. Upon further analysis of the profile, a characteristic was found for which the Universal Unique Identifier (UUID) of the service and the characteristic itself was found and as such this was the one that ended up being used to store the device's owner server's address. Since the device was already set to work as a pheripheral and it now stored the information relevant to the system, there was no need to do further work.

B. Server

The webserver was implement in Python 3 programming language. The program implements a simple tcp server capable of receiving multiple request at the same time. Each request starts with information sent from an application which include a pair of MAC address and associated RSSI value for each ble device that the same application found. Afterwards the list of pairs is filtered in order to remove any existant devices that are not present in the server's database of devices.

Each server has a database that includes only ble devices. An entry (description of a device) in this database is composed by the device's mac address, its longitude and latitude and its building, floor and room name. In addition to the database, a server when initiated can store additional location info such as the server's street, number, zipcode, city and country, allowing this information to be transmited to the client in order to offer an additional level of location description to the user. The whole location specific information can be visualised in figure 9.

Upon having filtered the initial list of pairs, the Cell of Origin (CoO) technique is applied by verifying which of the devices produced a stronger signal on the receptor. Upon obtaining the closest device an answer is sent to the application containing all of the information associated to the server and the selected device.

- Describe the Database (insert image example of database with a few entries??)

- Mention capability to Insert aditional info, at the moment it displays geocoding on pop up menu in figure 9.

C. Application

The Smartphone application was developed for Android using the Android Studio IDE. The Application is divided in two primary functional blocks, the Mock location Provider and the Google Maps Integrated Display, as can be visualized in figure 5.

The Mock Location Provider is implemenented as if it was a Location provider, such as gps. The application functions works as a listener to a Location provider, in this case it listens to the Mock Provider that was implemented. By implementing the whole process of obtaining a location inside a service (the mock provider) , a new level of abstraction is added to the application. As such, whenever the application is signaled to obtain the user's current location, a request is made to the associated location provider and the application only need to listen for the answer that eventualy arrives.

The Mock Location Provider incorporates the first three steps present in figure 7, which will now be explored individualy. The first step indicates the gathering of information of

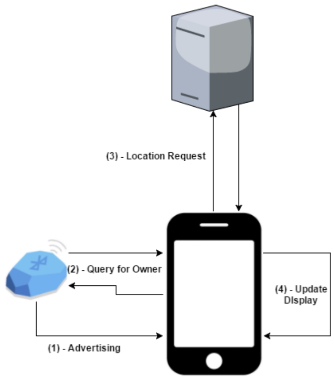

Fig. 7: Mock Location Provider Workflow

the surroundings of the user's device. When a request is made to the provider, a scan for nearby bluetooth low energy devices is made which will put the smartphone in a state of listening for incoming ble advertisement packets for half a second (NEED TO VERIFY VALUE AND JUSTIFY, THERE WAS A PAPER ON THIS TODO). During this scanning period, each time a device is found, the advertisement is registered in a list, which have a duplication prevention mechanism implemented. Once the period is over, the provider has avaliable a list of all the ble devices within range.

The second step involves taking the created list of devices, obtain a server adress and forward the same list to it. Once the first step is completed, the provider will analyze each entry at a time. For each device the provider will attempt to respond to the caught advertisement packet, resulting in a created connection. Once the connection is created the provider asks for the available services of the paired device. Upon receiving an answer, the list of services is swoop while looking for the service with the wanted UUID. If the device doesn't have the UUID that the provider is looking for, it can assume that the paired ble is not a beacon of our system, as such the connection is terminated. When the provider identifies that the device has the system's UUID, it requests the device to provide the service's existant characteristics. The provider will receive a list composed of the service's characteristics and it will search in it for the system's characteristics UUID, the one which contains the device's server's address. This search has the objective of confirming that the service existant in this device is indeed the one that was implemented for the system and not a device with another service that happened to have the same UUID. For any service outside those that are documented in the Bluetooth Special Interest Group (SIG), who have a specific UUID attached to them, the UUID is generated randomly and as such there is a small chance of collision. Once the wanted characteristic is found, the provider requests the device to read its value and stores the received value in a list. This list will contain the servers of the devices that were found, and for each address there will be a list corresponding to each device , and their corresponding rssi values, from the same owner. In order to quicken the previously described process, the provider keeps in cache the most recent contacted devices. Before attempting a connection, the provider confirms that the device isn't found in cache and when finishing a process, the associated device is inserted into the cache.

When every device has been contacted, a voting system is actioned which will decide from the list of servers which one it will send the collected information to. The voting system uses an exponential function in order to attribute a weight to each server. INSERT FUNCTION AND EXPLAINATION.

The voting system was implemented with the objective providing a thin security layer by allowing multiple devices of the same server to overcome a single attacker's device which happened to be close to the user. After obtaining each server's values, the one with the highest value is chosen and sent the list with all the devices.

The Third step involves a simple client/server tcp interaction. The application starts off by formulating the message that it will later on send to the server, this message includes all pairs of device mac address and its associated rssi value captured by the application on the first step. Once the message is computed, the application attemps to create a connection with the server at the chosen address at the end of step two. With the connection established, the message is forwarded to the server and the application is put onto blocked state where it awaits for an answer. Upon arrival, the answer received is checked for valid location, its information is process and the connection is terminated. The information contained inside the received message, which was described in section IV-B, is then processed into the adequate class capable of storing a geographic location and the same is broadcasted from the mock location provider to its listener.

One of the current limitations of the android API that deals with BLE is that the interface on the smartphone that is used to connect with a device has a fixed timeout time. MIGHT JUST NEED TO BE IMPROVED TODO

The Google Maps Integrated display is implemented using the Google Maps Android API. By using Google Maps it was possible to aliviate the weight on application since there wasn't need implement file transfer of indoor building's maps from each dedicated server to each request, which aliviated the servers aswell since there was no need to store its associated building's maps on it. Managing the maps was something that was aswell fortunately unnecessary and as such all these features were provided by google maps service. By making this development choice, the system as whole became closer to the desired generic approach while making possible for seamless transition between indoor/outdoor maps. The only imposed restriction is related to the addiction of new indoor maps onto the google maps, which is possible and well documented but dependent on a third party.

The Fourth step is called when the application receives a proper location from the request made onto the location provider. With the device's location known, a marker is placed on the map with the obtain coordinates (longitude, latitude), the camera is moved in order to be centralized on the position and fully displaying the indoor level map, and the menu visible on figure **??** is updated with the information that is bundled with the received location. In order to show the correct level on a multi level building, the "floor" information present in the menu is utilized. The API allows for obtaining a list of

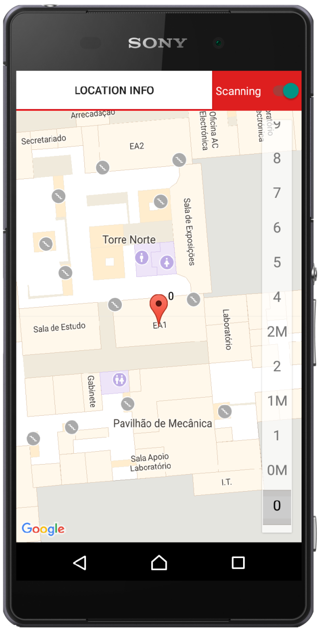

Fig. 8: Application screen showing a focused location on a room

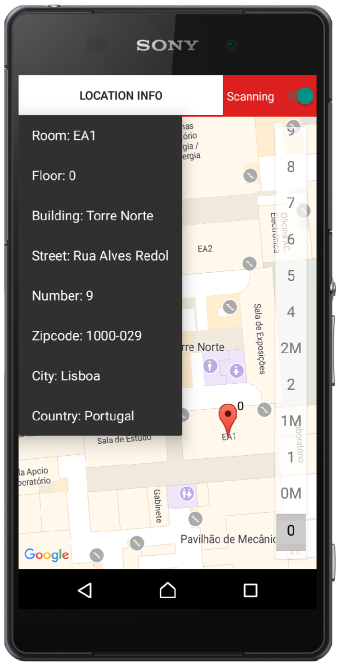

Fig. 9: Application screen showing additional information of location

existant levels on which the maps' camera is focused and as such it's possible to find out to which level the provided locaiton belongs and make so that the application shows it.

The pop-up menu was implemented to demonstrate the capacity of providing additional information associated with each location, be it geo-location taxonomy as it is currently implemented or possibly a description of the located room, an hyperlink of some sort or any other type of data that someone implemented this system would like to provide to its users.

The final state of the implemented system can be visualized in figure 8 and figure 9. The first displays the case of obtaining a location, where the marker has been placed and the camera zoomed

V. Performance Analysis

- Energy Consumption in general
- Energy consumption vs Cycle time vs Accuracy?
- Location Accuracy
- Time for request completion
- Data Requiremnts?

VI. Future Work

- Possible Improvement: Paralel ble connections; Improvements on lateration algorithm; Rest depends on the Performance results
- Conclusions

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