Analysis of Bluetooth Low Energy Detection Range Improvements for Indoor Environments

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Abstract. Real Time Location Systems (RTLS) research identifies Bluetooth Low Energy as one of the technologies that promise an acceptable response to the requirements for indoor environments. Against this background we investigate the latest developments with Bluetooth especially with regards its range and possible use in the indoor environments. Several different venues are used at the University to conduct the experiment to mimic typical indoor environments. The results indicated an acceptable range in line of sight as well as through obstacles such as glass, drywall partitions and solid brick wall. Future research will investigate methods to determine the position of Bluetooth Low Energy devices for possible location of patients and assets.

Keywords: Bluetooth Low Energy, BLE, Real Time Location System, RSSI, Indoor Positioning

Introduction

Over the past several years, indoor localization has grown into an important research topic, attracting much attention in the networking research community [1]. The increase in popularity for positioning services offered by smart devices and their related technology has indicated a turning in the field of indoor localization [2]. Our ultimate goal is to design a cost effective and efficient RTLS within the constraints identified in our previous paper [3] for indoor environment in particular a Healthcare environment. Previous work by [4] also evaluated the technologies for indoor RTLS as well as identified the methods used in determining locations. This paper determines the possible range and throughput similar to quantitative technological evaluations by [5] with Bluetooth LE in different scenarios of an indoor environment. Future work will explore Bluetooth LE mesh networking for indoor localization to enhance scalability and detection range.

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The rest of the paper is organized as follows. Section 2 illustrates the basic concepts of indoor localization. Section 3 defines the methodology used to conduct the experiments and obtain the results. In section 4, the authors discuss the results obtained from the experiments. Thereafter conclusions and future work are discussed.

Literature review

Technologies and techniques for RTLS

A number of different technologies have been tested for use in RTLS in the past with varied levels of success. However, due to the availability of newer technologies the best technology within the constraints need to identifed for possible use for indoor RTLS. Pancham et. al. evaluated the most popular technologies of RTLS published in recent peer reviewed works. The most appropriate attributes in terms of Real Time Location System (RTLS) from literature as well as from an exemplar for a typical indoor environment such as Healthcare were chosen to assess these technologies. In addition to the exemplar of a hospital, survey data of 23 US hospitals [6] was used in the evaluation process. In our previous paper review of literature we investigated technologies such as WiFi, Bluetooth and RFID and determined evaluation criteria to be cost [7], energy consumption [8], detection range [7], size and accuracy [9]. A typical domain such as Healthcare has other constraints such as electromagnetic interference [10], [11] which we now mitigate with low power transmission level but space constraints limited our selection to the most appropriate and the most common attributes.

Attempts to mitigate these constraints using popular RTLS technologies researched by [4] include Radio Frequency Identification Devices (RFID), Bluetooth classic, Bluetooth LE, Zigbee and Wi-Fi. Lee et. al. compared BLE and ZigBee technologies and used a single fixed distance of 1 meter and did not have conclusive results indicating which technology is better as wireless transmission is greatly affected by practical situations, such as the realistic environment interferences [5]. However this expirement did not provide measurements of aspects such as RSSI, throughput beyond this fixed distance which is needed for a proper network technology evaluation for the fixed distance.

A number of different methodologies exist to increase the accuracy, the most popular being the RSSI technique which increases accuracy to 1-2 (meters) [12]. An available improvement of RSSI involves a Kamlan filter which increases Bluetooth accuracy to 0.47m but at a cost of increased size (due to larger storage requirements) and increased power consumption due to increased computational cost [7]. As can be seen these RSSI and Kamlan filter techniques adds to the size form factor for Bluetooth and energy consumption. An example of Bluetooth system is Bluetooth Local Infotainment Point (BLIP) [13] which is a managed network offering access to LAN / WAN via Bluetooth [14]. Such a network will require a number of BLIP nodes to which the bluetooth devices will connect to due to its limited range. These bluetooth nodes then provide access to the LAN / WAN. With the advancement of Bluetooth LE such nodes will be minimized or eliminated depending on the environment.

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Bluetooth classic also has drawbacks in crowded areas due to signal attenuation and interference. Bluetooth classic can transfer large quantities of data, but consumes battery life quickly and more costly than Bluetooth LE or other indoor localisations technologies[15]. In addtion accuracy for RTLS differs at a cost in term of power consumption, size of device, and other factors. This gave birth to Bluetooth low energy (BLE) which is suitable to exchange small amounts of data consuming lower energy at a cheaper cost.

Bluetooth LE

Bluetooth Low Energy (BLE) is the power-version of Bluetooth that was built for the Internet of Things (IoT) making it perfect for devices that run for long periods on power sources, such as coin cell batteries or energy-harvesting devices [16]. One of the two systems of this version is Bluetooth low energy which transmits small packets of data whilst consuming significantly less power than the previous version of Bluetooth [8] . A BLE RTLS typically consists of a stationery anchor to detect the tags, a tag and the location engine to calculate the location [17]. BLE is an improvement and a later version of Bluetooth (BT) offering several advantages such as smaller form factor, lower cost and extended coverage. The point-to-point communication of the current BLE nodes have only limited coverage over a short range. Hence the proposal of a wireless mesh multi-hop network that has multiple nodes that are capable of communicating with each other to enable routing of packets to extend this limited coverage as a possible solution [18]. This distance can be extended further with the combination of current technologies that are more efficient.

Bluetooth® 5 released on 6 December 2016 is a transformative update on previous versions that significantly increases the range, speed and broadcast messaging capacity of Bluetooth applications. This version quadruples range and doubles speed of low energy connections while increasing the capacity of connectionless data broadcasts by eight times [19], [20]. These will impact on reliability, robustness, responsiveness. This latest version of Bluetooth will have quadruple the range, double the speed and an increased broadcasting capacity of 800% as compared to the Bluetooth Classic [21].

The earlier Bluetooth Classic version uses 79 channels with 1 MHz spacing whilst Bluetooth LE uses 40 channels with 2 MHz spacing in the unlicensed industrial, scientific and medical (ISM) band of 2.4 GHz. The range for Bluetooth LE extends from 2402 MHz (RF channel 0; logical channel 37) to 2480 MHz (RF channel 39; logical channel 39). Three channels (logical 37, 38 and 39) are so called advertising channels; logical channels 0 to 36 are data channels. The advertising channels are positioned so that they are not disturbed by the non-overlapping WLAN channels 1, 6 and 11 in the ISM band, see Figure 3.1. Bluetooth LE now can provide the higher transmission speeds as a result of the increased 2402 MHz wider channels as compared to the Bluetooth classic 1 MHz channels. In addition to higher transmission speeds more data can be transmitted within these channels as a result of the higher transmission frequency.

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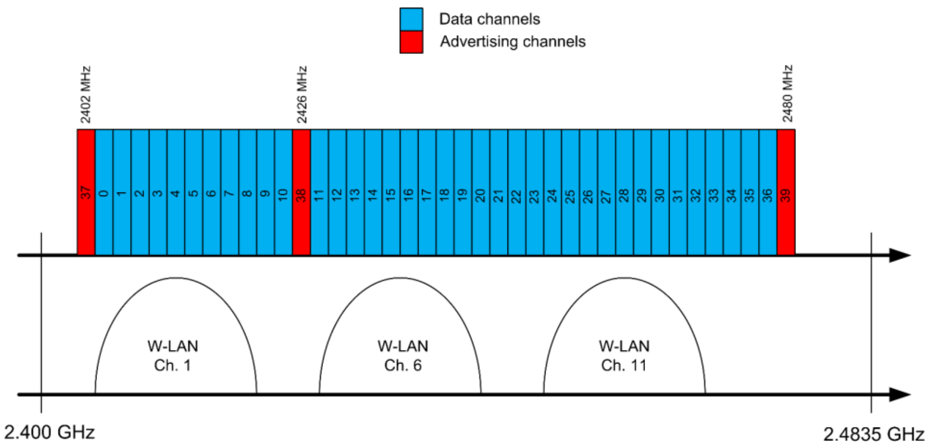

Figure 3.1 Bluetooth LE channels.

Use of Bluetooth LE in an indoor environment

In order to understand the technologies used in indoor RTLS one must look at the early developments in this domain such as the RADAR system. This system was one of the first developed indoor positioning systems that use radio beacons and Received Signal Strength Indicator (RSSI) measurements for localization [2]. A number of authors have used RSSI for indoor location together with various methods such as triangulation, trilateration and fingerprinting to improve its accuracy. These different methods are required to improve the range as obstructions such as partitions, walls etc. cause degradation of the signal strength and in some cases completely blocked signals [22]. However, the determination of the indoor position of sensors is outside the scope of this paper.

Methodology

Our approach was to use Bluetooth LE to propose a cost effective indoor RTLS solution with low power consumption, scalability, and long detection range. In order to determine the maximum range that can be obtained within the constraints we used experimental methods to mimic and indoor environment given a Bluetooth LE v5 signal transmitted at the lowest energy level of -20dBm. The aim of this experiment is to determine the maximum usable range indoors at clear line of sight, as well as through obstructions such as through glass door, dry wall and brick wall. Such obstructions represent partitions that would separate offices etc. in an actual indoor facility, hence representing as close as possible the actual environment. This methodology has sections that describe in detail the hardware selection and software configuration and the environment used for the experiment.

The experiment used the transmitted power level and packet size as independent variables. The power level was kept at the lowest level to establish the ranges and speed

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of transmission. The dependent variables were distance, obstructions resulting in different RSSI, throughput and length of time measurements. Using these variables, the following steps were used during the experiment:
Step 1: Measure and label the different predetermined distances.
Step 2: Setup the software on the Preview Development Kit (PDK)'s.
Step 3: Place the tester PDK at a fixed starting location.
Step 4: Place the responder PDK at the first measured point.
Step 5: Commence measurement of the RSSI and throughput.
Step 6: Move responder PDK to next measured point and repeat step 5.
Step 7: Stop when measurements are unusable or PDK's are disconnected.

Hardware selection and software configuration

The hardware used for this experiment were two Nordic nRF 52840 PDK. Segger Embedded Studio was used for application development and testing as well as deployment onto the nRF 52840 BLE System on Chip (SoC). The selection of this latest BLE SoC was based on the many advantages identified by [20]. Nordic was selected as the preferred supplier due to its price advantage, feature set and availability over comparable features of SoC from Texas Instruments.

The software was set up to measure the throughput with Maximum Transmission Unit (MTU) size of 247 bytes, connection interval of 7.5 ms and the Physical layer (PHY) data rates was set to 2Ms/s. The Physical (PHY) layer of the Nordic nRF52832 and prior SoC's transmission was limited to 1 Ms/s as per the Nordic design specification [23]. With the advancement of technology, the latest NRF52840 SoC allows for transmission of 1 Ms/s or 2 Ms/s. Our intention is to implement the SoC in an indoor environment and hence the decision to test at the lowest transmission of -20dBm to investigate the range and throughput. Broadcasting at the lowest level will limit the interference on other equipment and allow for more devices to be used within the same bands. One of the PDK boards was set as the tester whilst the other PDK board was set at the responder. Given limited resources, we relied on a single receiver-transmitter model. The tester sent out 1 MB of data and then queried how much of data was received by the responder. This tester PDK was connected to a laptop where Putty (a terminal emulator) was used to read the data via the USB interface. The measurements were repeated five times for each of the different distances in order to obtain an average reading. If the results showed a wide variance, the plan was to repeat the experiment multiple times. Once the data was captured the averages were calculated and reported.

Experiment environment

The three different venues selected together with the measured distances to conduct the experiment mimicked different areas and hence is a close replica of an indoor environment similar to other research conducted [24].

The first venue selected was a multipurpose hall that is approximately 25 square meters made of brick with glass doors on two opposite sides. Desks were placed at the

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measured intervals on which the PDK boards were placed. Data was collected at 5 meter intervals up to a distance of 25 meter within the hall and across obstruction such as the glass door and the brick wall where the PDK's were placed on either side of the obstruction.

The second venue was the board room that is approximately 20 meters in length and made of glass panels and dry wall partitioning. Data was collected at 1 meter intervals up 5 meters and thereafter data was collected at 5 meter intervals. Data was also collected with the glass door obstruction and the PDK's set from 2 to 6 meters apart.

The third venue was an office floor of offices separated with dry wall partitioning. Tests were conducted to establish the connectivity and possible range that could be obtained through the different partitions. The different directions that were used for the measurements conducted for the office area are depicted in figure 5.4. Measurement 1 was conducted in a straight line with only the dry wall as the obstruction. These measurements were taken from 1 to 6 meters at intervals of 1 meter. The second measurement indicated by measurement 2 in figure 5.4 was conducted diagonally down a passage at intervals of 1 meter up to 11 meters. Measurement 3 was also diagonal but this time through three dry wall partitions as obstructions. This was done mainly to establish the maximum possible range. Measurement 4 was through a solid brick wall as the obstruction to confirm the loss of signal strength during its penetration through the brick wall.

Results

Data was collected in the hall, boardroom and the office. Figures 5.1, 5.2 and 5.3 indicate the RSSI, time and throughput for a distance up to 25 meters. The data for the different attributes for the different venues are grouped together and indicate in their respective attribute graphs due to space constraints. The different colors in the legend indicate the different venues with their respective obstacles. In the hall the measurements were taken at 5 meter intervals until the connectivity and transmission was unacceptable and data not usable. The measurements noted whilst the PDK boards were placed at different angles were not significantly different. Therefore, there additional measurements were not considered in the final analysis.

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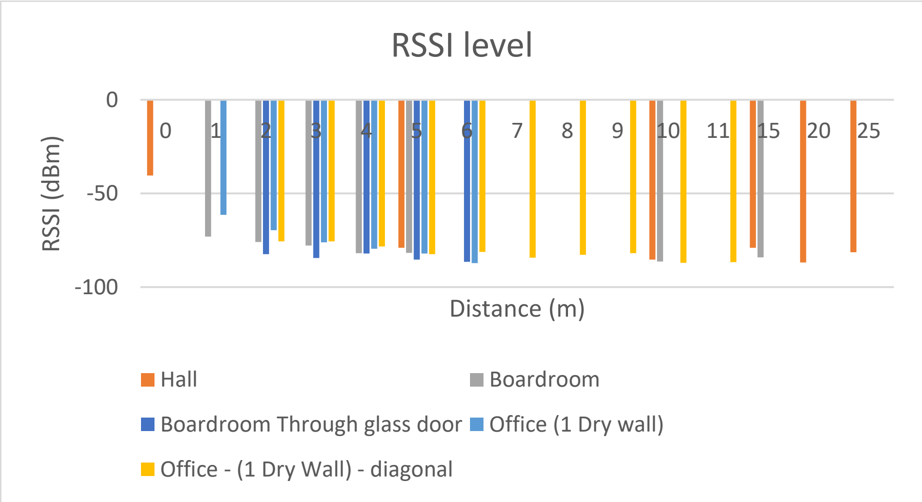

Fig. 5.1 RSSI levels

In the boardroom, measurements were taken at 1 meter intervals from 1 to 5 meters and thereafter measurements were taken at 5 meter intervals up to the maximum usable distance. Thereafter a glass door, forming an obstruction, was placed dividing the boardroom into two sections. The PDK boards were placed 1 meter on either side of the glass partition for the initial measurement. Thereafter the test PDK was moved at 1 meter intervals up to 6 meters. At 6.5 meters the boards could not communicate through the glass door.

In the office environment, a good throughput was obtained for measurement 1 shown in figure 5.4. Good throughput was also obtained up to 11 meters for measurement 2 and beyond this connectivity was very poor. Throughput for measurement 3 was good up to approximately 13 meters. Good throughput was obtained for measurement 4 at a distance of 5 meters but thereafter the connectivity was very poor due to the loss of signal strength through the solid brick wall.

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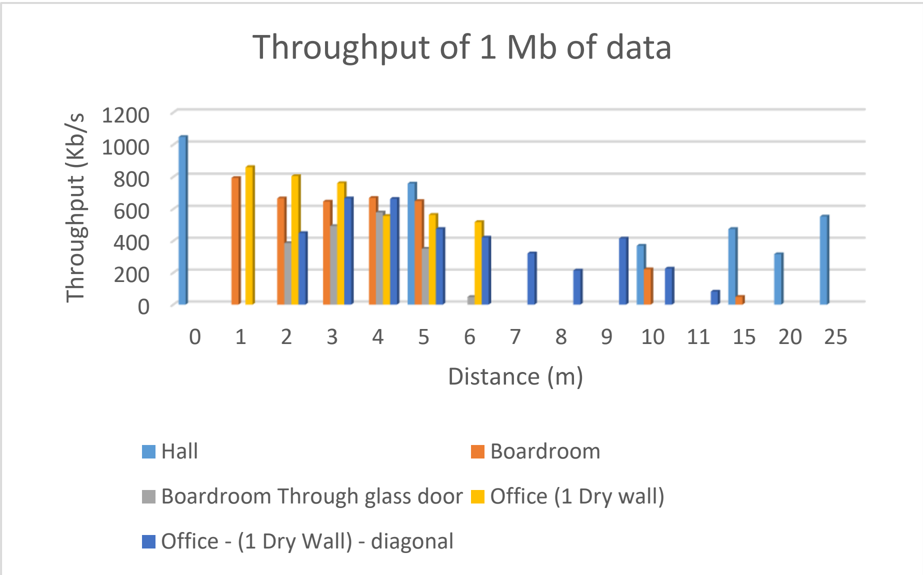

Fig. 5.2 Time to transmit 1Mb of data

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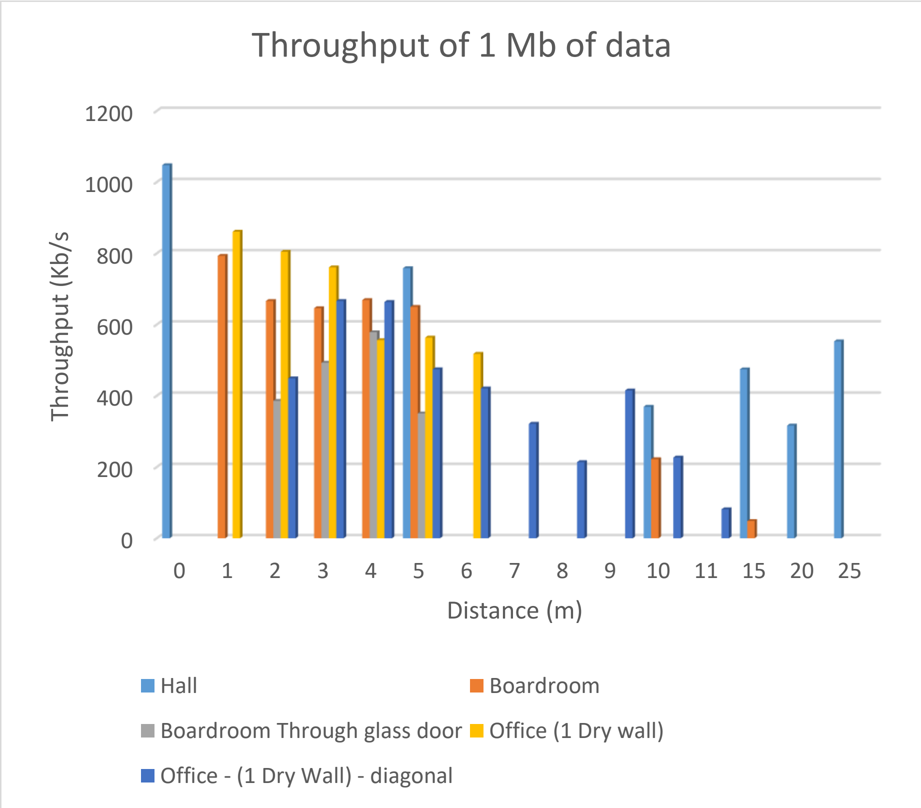

Fig. 5.3 Throughput of 1 Mb of data

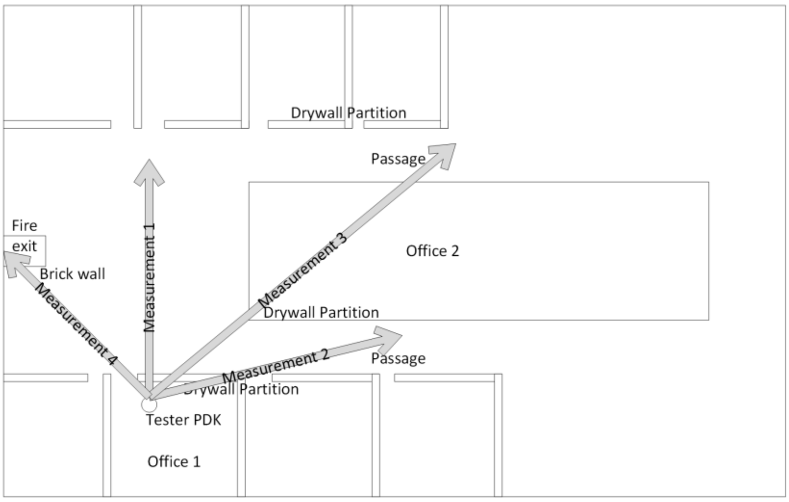

Fig. 5.4 Layout of office area

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Discussion of Results

The time to transmit 1 Mb/s of data and throughput follow a nonlinear pattern which suggest that there are potential interfering variables in this experiment. Given the constraints, these interfering variables could not be isolated within this study.

A range of 25m was obtained when transmitting at a level of -20dBm in clear line of sight within the hall. The throughput of 759 Kbps at 5m and 533 Kbps at 25m indicates that data can be transmitted at longer ranges at higher speeds using Bluetooth LE v5. In the boardroom a through put of 793 Kbps at 1m to 222 Kbps at 10m was measured. However [1] obtained a transmission range of 2m using Bluegiga USB dongle as a gateway and a RadBeacon Tag transmitting at the same level. This indicates that the environment delivers different results. Possible reasons for this variance could be related to the size of the boardroom as compared to the open hall as well as the makeup of the walls.

An interesting observation was that when the PDK's were placed either side of a glass door at a total distance of 2m a lower throughput rate of 386 Kbps was measured compared to the highest throughput rate of 579 Kb/s obtained at a distance of 4m between the PDK's with the same glass door as the obstruction. At 5 meters the throughput was similar to that measured at 2 meters. However, the throughput at 6 meters deteriorated to 48 Kbps and at 6.5m to an unacceptable level and in most cases disconnected completely. The RSSI measurements had little variation from 2 to 6 meters. These readings across a class door are interesting as there may be reflections of the electromagnetic waves on the glass.

Measurements in the office area by figure 5.4 show that connectivity is possible up to a distance of 11 meters and 13 meters in the two passages respectively. This indicates that the Bluetooth LE signal transmitted at -20dBm can penetrate a door and multiple drywall partitions. However due to the weakened signal the distance is not great. The throughput dropped from 227 Mb/s at 10 meters to 82 Mb/s at 11 meters. Connectivity in the fire escape was acceptable behind the closed door but was unavailable at 5 meters indicating that the brick wall had a serious negative impact on the signal strength. The results indicate that in clear line of sight signal strength and throughput is good but when obstructions such as glass, partitions brick wall etc. are placed in the path of the signal the signal strength deteriorates rapidly. This loss increases when the obstruction such as a brick wall is denser as identified in the literature.

The long range and high throughput results obtained for the lowest power level used is encouraging for use in an indoor environment. For pure data transmission, given that Bluetooth LE sensor is stationary and a connection is established, an acceptable throughput can be obtained. For an RTLS, multiple sensors and methods must be used to determine location with a high level of accuracy.

The variance in the results represent an actual environment as we have noted a pattern within certain environments and random changes at certain distances e.g. at 15 meters in the hall, the throughput improved. This indicates that there is a nonlinear relationship as distance increases. Another example is that in the boardroom the throughput dropped significantly between 5m to 15m. However, RSSI results indicate that it is possible to identify a Bluetooth device with a degree of accuracy (in an open

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space an RSSI level of approximately -80 dBm indicate a distance between 2 and 25 meters, in an office environment an RSSI level of approximately -80 dBm indicate a distance between 2 and 13 meters, whilst in the boardroom an RSSI level of approximately -80 dBm indicate a distance between 2 and 6 meters. The RSSI level was measured in anticipation of future work to use this aspect as part of location determination.

Conclusion and Future work

The primary focus of this paper was to test the latest Bluetooth LE v5 PDK's range and throughput in an indoor environment for future use in an RTLS. However, an accurate and reliable RTLS system within the constraints of an indoor environment such as Healthcare requires a well-designed architecture. The results obtained are promising to be used in an Indoor environment for data transmission as well as RTLS.

RTLS in Healthcare has the potential to enable efficient location of patients, employees and equipment. Although RTLS have realized benefits in some cases, further research was called for to reduce the serious technical impediments such as obstacle obstruction of signals to its implementation including asset management [6]. As a consequence, we researched the latest Bluetooth LE to establish through experimentation the possible range as well as the level of penetration through obstacles. Bluetooth LE can be configured into a low cost low energy network architecture enabling lower energy consumption [25] and extending the range. A combination of multiple methods such as triangulation, fingerprinting [26], block chain architecture and repeater tags (tags configured to forward messages) will be used to increase the location accuracy whilst minimizing energy consumption. Further research will be needed especially with regards RSSI measurements with their distances to expand on this paper's findings. The use of BLE devices, with low power consumption will extend battery life thereby reducing maintenance [5]. Due to the high volume of patients as well as the size of hospitals, especially those in the public sector, cost is an important constraint.

Some of these challenges such as network range can be realized by using mesh networks as well as intermediate sensors to link to other in the near vicinity. With the latest technology used unlike its predecessors the Bluetooth LE devices can form a mesh network to extend the network with the lowest possible energy consumption. A more detailed experiment with different values for variables such as transmission power levels, data packet size etc. will be conducted for improved and accurate performance in terms of indoor real time location. The results of this will be published in future articles. Furthermore, a prototype will be setup in a typical indoor environment such as Healthcare to test viability of the processes and newly designed architecture.

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