

Analysis of Bluetooth Low Energy RSSI Values for Use as a Real Time Link Quality Indicator for Indoor Location

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Abstract. Technologies that can be used for location outdoors are readily available using Global Positioning Systems (GPS) whilst technologies used for indoor location still prove to be a challenge. Technologies such as Radio Frequency Identification (RFID), Bluetooth, and Wi-Fi, together with location algorithms that include optimization, still require further research for large-scale deployments. This study adopts Bluetooth Low Energy technology and uses the Received Signal strength Indicator (RSSI) from messages as a data source. We then analyse the RSSI from Low Power Nodes, their calculated mean, median and mode values as a basis for further use in an indoor real time location system. Fingerprint databases have been used extensively as a reference to determine location. However, due to the changing indoor environment these may become outdated very quickly. Therefore, this study proposes the use of a Link Quality Indicator as a reference point for further calculation of the location of an asset or a person. The Nordic System on Chip (SOC) is used as the low power node together with a series of Raspberry Pi gateways. Results show that the mean and mode can be used in combination to filter and smooth RSSI values. These calculated RSSI values can then be used and as inputs for an indoor location engine for location determination.

Keywords: Real Time Location System · RTLS · RFID · Indoor positioning · Bluetooth low energy networks · Mean · Moving average · Mode · Link Quality Indicator

1 Introduction

For many decades, researchers have sought ways to track assets and people indoors. Recently technologies such as BLE [1], Ultra Wide Band (UWB) [2–4], visualization from video recordings [5], Wi-Fi [6], visible light positioning [7] are still being researched for implementation for indoor tracking. Furthermore, the availability of hardware has prompted new research in localization and navigation especially for indoor environments. Tracking both objects and the public outdoors is feasible using

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Global Navigation Satellite Systems (GNSS). Similarly, localization of both people and objects is a requirement for many indoor applications. This must be achieved with a reasonable degree of accuracy within indoor environmental constraints. There is also a need to locate the position of objects and people indoors at real time. Real time indoor positioning is not possible using GPS technology [8] as the tracking device requires a direct view to several positional satellites [9]. Therefore, alternative technologies for indoor location are required for implementation in real world applications. According to [10], a Real Time Location System (RTLS) can be defined as a "combination of hardware and software that is used to continuously determine and provide the real time location of assets and resources equipped with devices designed to operate with the system".

The results of any system often depends on its inputs. For indoor location, this means that the location determined by the designed system depends on the inputs obtained for the related hardware and software placed in the environment. Therefore, this research is to evaluate and establish a sound data source as input to such a system for the purpose of location determination within the system's theoretical, social, environmental constraints. This paper is organized as follows: literature review, methodology, and research findings.

2 Literature Review

2.1 Review of Indoor Positioning Technologies

A number of indoor positioning technologies have been researched and proposed over the decades with varying levels of successful implementations. Some of these indoor positioning technologies include (RFID), Near Field Communication (NFC), Bluetooth and Bluetooth Low Energy (BLE). [11] surveyed indoor localization systems and reported that technologies using vision and active /passive tags had weaknesses such as poor performance, high cost, and installation complexity.

The reason that Wi-Fi is proposed as a solution to RTLS is that most indoor environments already have Wi-Fi infrastructure installed. A Wi-Fi system entails a Wireless Access Point (WAP) and a Wi-Fi device. The Wi-Fi device contains a Wi-Fi radio that is used for connectivity. Wi-Fi being a popular technology for indoor usage provides connectivity for most devices. Therefore an indoor RTLS could use existing Wi-Fi infrastructure to relay messages from Wi-Fi tags [12]. However, to use Wi-Fi for RTLS, additional hardware such as Wi-Fi access points are required for reasonable accuracy for indoor positioning of objects or people. [11] investigated wireless technologies because of their high availability and concluded that the solutions could not deliver the performance level required by applications. The coverage provided by the WAP will impact on the reception of the devices that are required to connect to the network. Other constraints include form factor, battery life etc. These factors together with the fact that Wi-Fi was not designed for RTLS make this technology unsuitable for an indoor RTLS.

RFID is another technology based on active or passive tags. A tag constitutes a chip that stores a unique ID and an antennae that is used to transmit and receive data [13].

RFID tags are used in diversified applications including retail, food and restaurant, logistics, travel and tourism, health care etc. [13] identified two main technical issues with RFID systems. The first is where reader collisions occur when multiple readers read a single tag. The second is tag collision occur where a reader reads many tags at the same time. Both these types of collisions result in difficulty in determining the individual identities of tagged entities. Other issues identified include signal interference and privacy.

Despite the use of RFID systems for a number of years, a number of issues still need to be addressed. One of the problems highlighted by [13] is that models researched by academics are not implementable in real-world settings and eventually do not help the practitioner. Challenges experienced in implementation of these models prevent wide scale rollout. Three main difficulties in implementing RFID systems discussed by [14] are related to the high cost of infrastructure and tags and its uncertain return on investment; technical issues such as electromagnetic interference and distractions by metallic objects in reading tags; and security and privacy. The high cost of implementing solutions to mitigate these difficulties makes it unfeasible and hence not scalable.

A newer technology based on NFC is a passive one way identification technology for very short distances requiring no batteries for its tags as power is electromagnetically induced with an NFC reader in range [15]. This technology works well for transmission of data only for short distances i.e. a few centimeters. Therefore, it is unsuitable for use in an RTLS.

Another wireless technology for communication over short distances is Bluetooth. Signal interference and attenuation of Bluetooth classic signals poses serious drawbacks in crowded areas. Although Bluetooth classic can transmit large quantities of data, it does consume battery power quickly and is more costly than Bluetooth Low Energy or other indoor localizations technologies [16]. Furthermore, accuracy for RTLS differs at a cost in terms of form factor, power consumption, and other factors. In particular the smaller the form factor the smaller the battery size. This results in less power being available and hence consumption needs to be reduced. Development in the Bluetooth space resulted in Bluetooth Low Energy suitable to exchange smaller amounts of data while consuming lower energy and be available at a lower cost. However, BLE compared to Bluetooth (BT) and NFC offers several additional advantages such as lower cost, smaller form factor etc. When combined with beacon technology BLE can achieve coverage of distances of up to 50 m [17]. [18] identified that BLE nodes only has limited coverage over a short range when using point-to-point communication. They proposed using multiple nodes in a multi-hop network using a wireless mesh configuration. These nodes communicate with each other to enable routing of packets thereby extending the previous limited coverage range. Technologies and algorithms that are more efficient can be used to extend this distance.

BLE is more attractive due to its low power consumption and ease of deployment [1], and small form factor [9]. The advantage of using Bluetooth Low Energy tags is that consumes low energy and has a low cost [19] as well. However, an important issue to consider is that most wireless signals suffer from multipath fading (variation of the attenuation) and /or shadowing (deviation of the power received) during transmission [20]. Consequently, more solutions propose use a combination of multiple technologies to minimize the disadvantages experienced in using a single technology. [19] evaluated

the reliability of detection and tracking of people with Bluetooth Low Energy tags. Their system consisted of a Tag that sends 2.4 GHz signals, a stationary anchor to receive signals and a local engine. The local engine collects received signal data and performs the calculations for the location of the tag based on this data. Their results were more reliable when tags were closer to the anchors, detection was unreliable for boundary conditions especially in penetrable walls, and hence more work was required to improve accuracy.

2.2 Location Determination

Different techniques such as trilateration [21] or finger printing, using Received Signal Strength Indication (RSSI) are used to determine locations [1] of objects or people. Trilateration uses multiple receivers to receive the messages from a transmitting node. Each of the receivers calculates the probable location using the received RSSI. In the case of finger printing a historic set of RSSI values are recorded by each receiver for each of the transmitting nodes. This database of RSSI values is referenced when a new set of RSSI values are obtained at real time. The closest match is found and their historic location is used as the probable location. RSSI is the most popular source of information from which distance estimation for wireless systems can be calculated with an average accuracy error of 1–2 m [22]. The use of the Kalman filter on Bluetooth RSSI values improves accuracy to 0.47 m. However, this use is at a cost of increased form factor (due to increased storage requirements) and increased power consumption [23].

Application of the Kalman filter is powerful technique but also requires a large number of RSSI measurements and calculations to enhance accuracy. Also processing and storage capacity is a limitation of this algorithm especially for Low Power Nodes (LPNs) [24]. Their simple prototype, with a rapid and dynamic approach and without detailed calibrations, delivered a fixed point positioning error of 0.47 m. As can be seen, the use of Kalman filter techniques applied to RSSI values increases energy consumption and increases the form factor for Bluetooth.

[25] used the Link Quality Index (LQI) in a ZigBee network for location both indoor and outdoor environment. This LQI is derived from the physical layer and is used from reference nodes in the network. For an indoor environment, the area is divided into zones and sub zones for further processing. Another popular technique to improve on RSSI as a source is to average the RSSI and then apply inter Ring Localization Algorithm (iRingLA) technique [26] for localization.

3 Methodology

This research focuses on establishing a reliable basis of RSSI values to be used as a LQI for indoor location. The intention is to establish a simple method in an initial phase for subsequent location determination. It is important for the basis of the data source to be reliable so that the error in the calculated position can be minimised. The hardware selected uses the latest technology available and the firmware has been customised specifically for this research. The research entails setup and capture of data from LPN's to a server for processing.

3.1 Hardware Selection and Software Configuration

In our study we used Skylab's SKB501 single chip solution shown in Fig. 1 as the Low Power Node (LPN). It is designed take advantage of the feature advancements of Bluetooth® 5. Also it takes advantage of Bluetooth 5's increased performance capabilities which include high throughput modes and long range. The Bluetooth 5 specification enables the NRF52840 and other similar SOC's to take advantage of the considerable performance improvements for BLE V5.

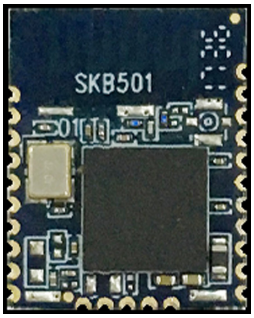


Fig. 1. SKB501 – LPN top view

The gateway used for this research is a Raspberry Pi 4 running Ubuntu server V18.04 forming the bridge between the LPN and the server. The gateways scan for Bluetooth messages from the LPNs, converts them and then pushes the data to a UDP server via a Wi-Fi network. The server runs an Ubuntu Operating System with a PostGreSql database. This high level architecture is depicted in Fig. 2.

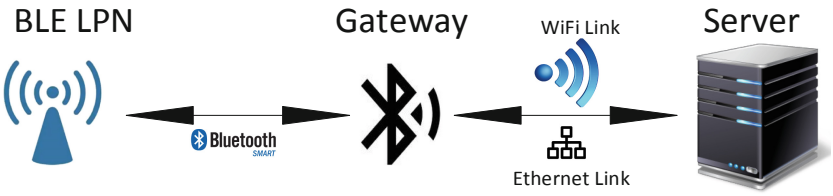


Fig. 2. Architecture

3.2 Data Collection

Firmware for the LPN was configured to broadcast the unique LPN identifier, transmit RSSI level and unique message identifier every 100 ms. The unique message identifier was used to analyse how each broadcast message was received at each of the gateways. The gateways named GW-001 to GW-004 were placed at the corners of a 2 m^2 area. LPN's named LPN001to LPN007 were placed at the positions depicted in Fig. 3. The LPNs 1, 3, 4 and 6 were placed adjacent to the gateways as well to establish the initial

signal loss experienced. The LPNs 2, 5, and 7 were placed at equal distance between the gateways to determine the similarity in RSSI received by the gateways. Positions are labeled as x, y where x is the horizontal measurement whilst y is the vertical measurement in meters. This depicted in Fig. 3.

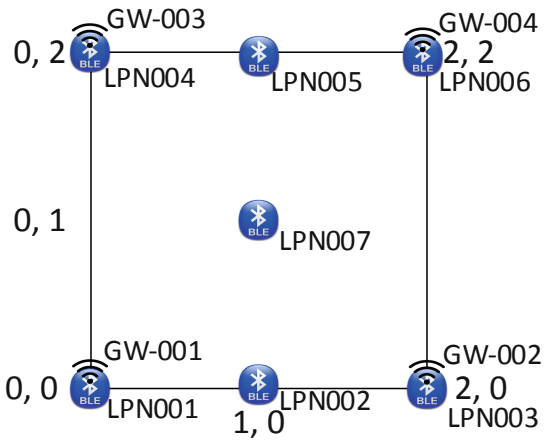


Fig. 3. LPN and gateway layout

Once the LPNs, gateways and server were setup the LPNs began broadcasting messages every 100 ms. These messages were received by the Gateways which converted them and uploaded them to the server. The time limit for capturing the messages used was 10 min and 30 min sessions.

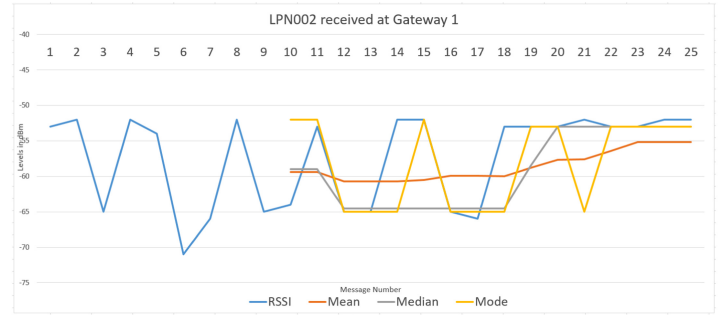
To obtain the filtered mean the formulae (1) was used to calculate the mean RSSI using a value of 20 for n. This meant that for each calculation a window of 20 RSSI values were used. The principle of first in first out was used the manage the RSSI stream.

$$Mean\ RSSI = 1/n \sum_{i=1}^{n} xi \tag{1}$$

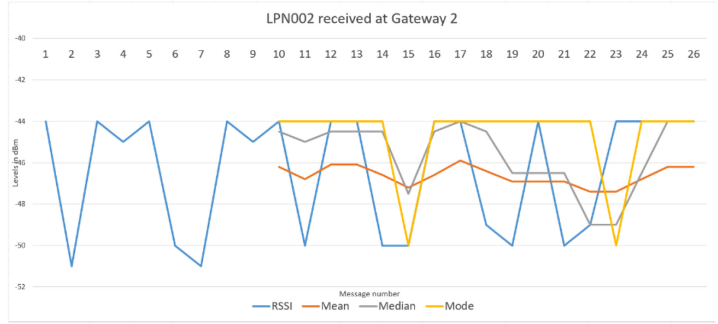
The mode indicates the element that occurs most often in a data set. However, in this research in addition to calculating the mode, the count for each unique RSSI occurrence is computed. The number of occurrences of the RSSI values is studied to determine a possible pattern to be used for further calculation.

4 Results

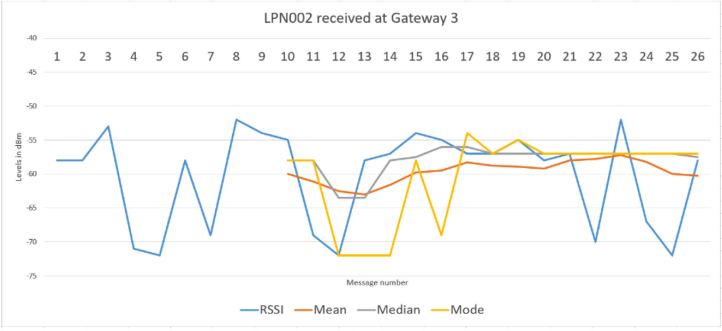
In excess of 152 000 messages were recorded from the LPNs. Figures 4a to 4d depict the actual RSSI, mean, median and mode. The RSSIs measured at gateway and depicted in the graphs are used for illustration as similar results were calculated for the remaining data set.



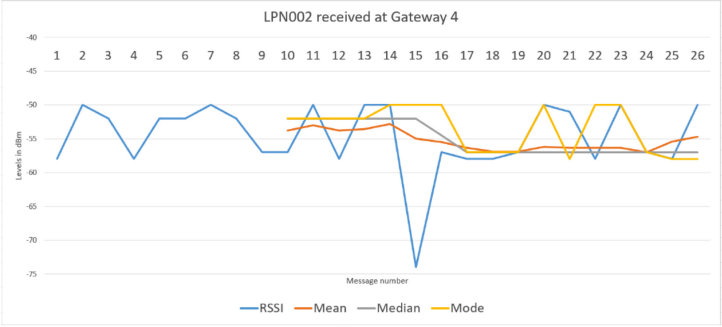
(a)



(b)



(c)



(d)

Fig. 4. a. LPN002 messages received at GW-001, b. LPN002 messages received at GW-002, c. LPN002 messages received at GW-003, d. LPN002 messages received at GW-004

Figure 5, which is used for illustrative purposes, shows the mode of the RSSI received at gateway 001 for messages received from LPN003. In addition, the graph also show the count of each of the unique RSSI values indicating the variation and distribution. In this case, this stability can be seen from the fact that the number of messages received are at levels −56 and −54 are 366 and 228 respectively.

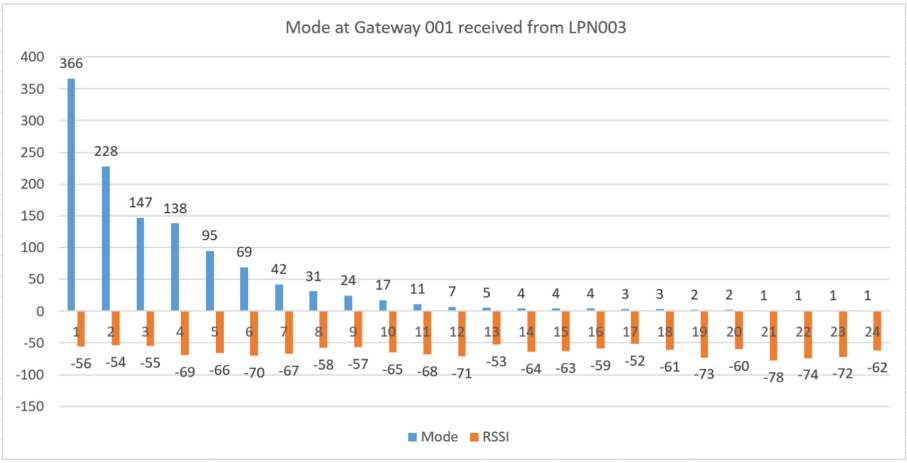


Fig. 5. Mode at GW-001 from LPN002

Figure 6 shows the mode of messages received at Gateway 2 from the LPN005. One hundred and forty one messages were received at level of −51 and 93 were received level −55. The graph also shows the count of unique RSSI values received. The RSSI count of remaining messages were much lower than the first two in both these examples. All readings were taken with the LPN and the Gateways fixed at the same positions as indicated in Fig. 3. This pattern has been identified generally across all of the data received and recorded. Therefore, one such sample is used for illustrative purpose.

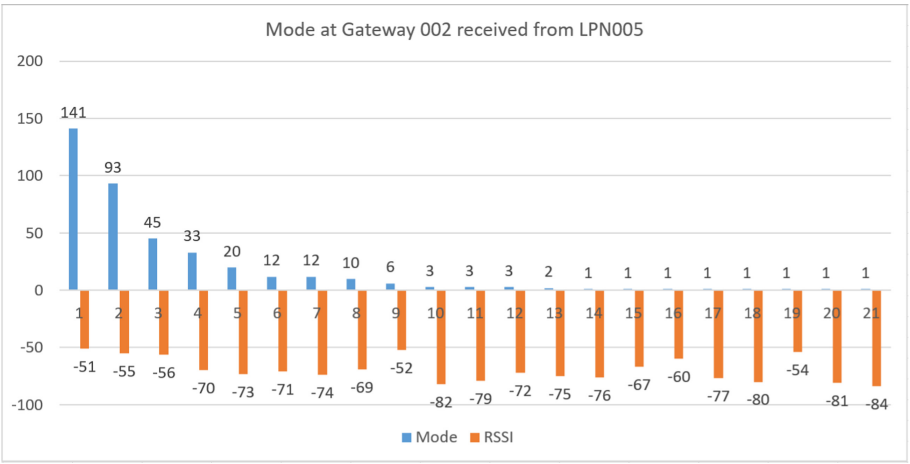


Fig. 6. Mode at GW-002 from LPN005

5 Discussion

The results obtained from this research, indicate that a reliable metric that is best suited for smoothing of the results is established. The moving average (mean) calculated from five RSSI values was not as reliable for the smoothing of the original RSSI for further use. After some detailed computation, it was found that the moving average (mean) calculated using ten RSSI values delivered a more reliable source for further computation. Hence, for the most reliable location calculations, a minimum of ten RSSI readings is recommended. The mean showed the best smoothing calculation followed by the median at each of the four gateways.

[27] improves the raw RSSI values by applying a factor between 0 and 1 to the current and previous RSSI values to obtain an improved RSSI value. This new RSSI value is therefore dependent on the previous and current RSSI values. They then apply a 20 value moving average to the newly obtained RSSI stream to calculate a smoothed RSSI. The RSSI values are then passed for further processing to determine the location. This has an additional step as compared to our proposed process. Is also uses twice the number of RSSI values to for the smoothing process adding to the complexity of the process of obtaining a data stream for further computation.

The mode calculated at each of the four gateways indicate that the RSSI stabilizes after a period and remains constant. A large percentage of the RSSI levels appear to be at the top three RSSI counts in most cases with the mode being more prominent when observed for a longer period. This pattern has been identified generally across the data recorded. Therefore, the combination of the mean, mode and RSSI values close to the mode proves to be a reliable basis to commence the calculation of the location. In this case, there is no need for a fingerprint to be captured, saved and referenced, as an indoor environment is a dynamic one. The changing indoor environment will result in different RSSI values reported each time. Also with the movement of people causing a

changing environment, the location becomes more difficult to calculate accurately. Therefore, this will warrant a more dynamic LQI to be used to determine the location of an asset or a person.

6 Conclusion

Cost effective applications of RTLS solutions can deliver much needed value in various sectors, for example health care. RTLS have improved over time and tremendous benefits are realized in some use cases. However, there is opportunity for research to overcome the serious technical constraints to be successfully used in applications such as asset management [28]. Computation for indoor location systems has proven to be complex and resource intensive. This because the number of RSSI values captured must be large in order to perform a reasonable calculation of the location in real time. Furthermore, the dynamic nature of an indoor environment resulting from electromagnetic interferences and obstacles require that the calculations for location use a dynamic data set.

This research has established a useful pattern as a basis to determine location with dimension reduction of signals. Future research will include establishing and testing a reliable RSSI data set using a combination of the mean and mode, using machine learning to determine location through obstacles, balancing computational system requirements and minimizing battery power usage in delivering a reliable location. Also at present since messages are broadcast at 100 ms intervals there will be 10 messages per second. A higher frequency would result in more transmissions resulting in more computations. Therefore, the moving average for both mean and mode will be investigated when messages are broadcast at a higher frequency within the constraints of an indoor RTLS. The most suitable metrics were established using simple calculations, which we hope to use when calculating mobile-tagged entities in the future. Then, the use machine learning will be used for further calculations of locations of moving objects around obstacles.

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