

Determining the Impact of Perspex Obstacles on Bluetooth Transmission Paths Within a Simulated Office Environment for More Accurate Location Determination

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Abstract. Research on Real-Time Location Systems (RTLS) for indoor environments establishes Bluetooth Low Energy as a promising technological low-cost solution for various environments. However, in indoor environments, there are numerous obstacles such as furniture, walls, partitions, etc. that will cause obstructions to Bluetooth signals. This research established the effect of Perspex on Bluetooth transmission in an indoor environment. This research extends on our previous research which evaluated RTLS technologies, RTLS constraints, and an energy efficient design model for sensor detection in indoor environments. Perspex was chosen for this research as it is used as a common shield used to minimize COVID transmission in an office environment. In general, the 3 mm and 5 mm Perspex did not have a significant impact on Bluetooth transmission.

Keywords: BLE · Bluetooth Low Energy · RSSI · Real-Time Location System · Obstacle · Obstruction · Perspex

1 Introduction

During the past few decades, with the proliferation and availability of indoor positioning hardware, this RTLS realm has developed into a significant research area, inviting interest from a variety of researchers [1]. The interest in location services provided by the Internet of Things (IoT) technologies identified a critical period for indoor real-time location [2]. Our eventual intention is to design an efficient and cost-effective RTLS taking into consideration the constraints documented in research work [3] for an office environment. Authors in [4] also explored the technologies relating to indoor RTLS and went further to determine the different methods that could be used in calculating locations. This research determines the impact of obstructions in particular Perspex in the path of Bluetooth transmission of Low Power Nodes (LPN) to gateways. Perspex is a clear acrylic sheet that is used as a screen to reduce transmission of COVID in office environments. Various

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thicknesses of this material are available, but the most popular thicknesses used are the 3 mm and 5 mm. These are used to partition spaces between employees or between employees and customers.

This paper is arranged as follows: Sect. 2 discusses the underlying principles of indoor location and Bluetooth technology, Sect. 3 defines the methodology used to conduct the experiments to evaluate the impact of Bluetooth signals through the obstacle Perspex, Sect. 4, presents the results obtained from the research, Sect. 5 discusses the results obtained from the experiment and Sect. 6 concludes and recommends future work.

2 Literature Review

2.1 RTLS Technologies

Research to track assets and people indoors has been conducted for many decades. More recently research on the implementation of indoor tracking technologies are being conducted on visible light positioning [5], Ultra Wide Band (UWB) [6–8], BLE [9], Wi-Fi [10], and visualization from video recordings [11]. Furthermore, the advancement and development of new hardware have delivered new solutions that have inspired new research in the field of indoor localization and navigation. Global Navigation Satellite Systems (GNSS) provides a feasible technology for tracking both people and objects outdoors. Similarly, many indoor applications necessitate the need for localization of both people and objects. In case of an emergency, the location of objects and people indoors needs to be determined at real time. Indoor environmental constraints require additional designs to provide a reasonable degree of accuracy. Using GPS technology [12] it is not possible to determine real time positioning indoors as the devices used for tracking require a direct line of sight to the different satellites [13] to triangulate the position. Therefore, alternative design models with different technologies must be used in real-world systems for indoor locations. According to [14], an RTLS constitutes a "combination of software and hardware that is used to repeatedly calculate and furnish the location of assets at real time to resources that are designed to operate with the system".

Various solutions used in RTLS have been evaluated. However, the advancement in technologies warrants the most appropriate solutions to be designed taking into account constraints of an indoor RTLS. [4] appraised prominent technologies of RTLS that were published in peer reviewed research articles. This research used the most common attributes in terms of RTLS within the healthcare exemplar and literature to assess these technologies. The evaluation process included data from 23 US hospitals [15] together with the exemplar of a hospital survey. In an earlier paper [3], we evaluated technologies such as RFID, Wi-Fi, and Bluetooth and determined evaluation criteria viz. cost [16], energy consumption [17], accuracy [18], detection range [16], and form factor. This preliminary research determines the effects of obstacles in particular Perspex on Bluetooth signals before data can be processed for accurate prediction of locations.

[19] used a single fixed distance of one meter to compare BLE and ZigBee technologies. However, they did not have compelling results that indicated which of the two technologies is superior as wireless transmission is largely affected by interferences in a realistic environment. Hence our research to more accurately determine the effects of one of the obstacles on Bluetooth in an office environment. Furthermore, their research did not provide measurements for throughput or RSSI beyond this fixed distance to report on the effects of the signals. Our research expands on their work to extend the 1 m range to cover an office as a more realistic environment for indoor location and tracking.

Bluetooth Local Infotainment Point (BLIP) [20] is an example of a Bluetooth system that offers access to LAN/WAN via Bluetooth [21]. Several BLIP nodes are required for such a network to allow the Bluetooth devices to connect due to Bluetooth's limited range. Due to the advancements of BLE the number nodes required will be decreased.

Bluetooth classic's limitation in densely populated areas due to interference and signal attenuation. Bluetooth classic can send large amounts of data, but depletes battery power quickly and is more expensive than Bluetooth LE or other indoor localization technology [22]. Furthermore, for increased accuracy for RTLS, there will be an increased form factor, increased power consumption, etc. With the advances in technology, Bluetooth LE emerged as a more suitable technology to transfer small packets of data whilst consuming lower energy and at a lower cost.

2.2 Bluetooth Low Energy

Bluetooth Low Energy (BLE) is designed for the Internet of Things (IoT) making it most suitable for equipment to work for long periods on power sources, such as energy-harvesting devices or coin cell batteries [23]. One of the key features is BLE can transmit small packets of data whilst significantly reducing the power consumption when compared to the previous version of Bluetooth [17]. A BLE RTLS typically consists of a tag, a stationery anchor to detect the tags, and the location engine to calculate the location of the tags [24]. BLE offers several advantages such as extended coverage, lower cost, and smaller form factor. The point-to-point nature of the communication of BLE nodes has limited coverage. Hence the proposal of a possible solution by [25] to extend this limited coverage by using a wireless mesh network that uses multiple hops to enable routing of packets from multiple nodes (sensors) to facilitate communication among the nodes.

The introduction of Bluetooth® 5 in 2016 provided the industry with increased speed and broadcasting capacity. Both BLE and Bluetooth Classic use 2.4 GHz in the unlicensed industrial, scientific, and medical (ISM) band. BLE uses 40 channels with 2 MHz spacing whilst Bluetooth Classic uses 79 channels with 1 MHz spacing, see Fig. 1. The increased 2402 MHz wider channels can provide higher transmission speeds as compared to the Bluetooth classic. Furthermore, the higher transmission frequency allows for increased data transmission.

With the rapid rise in COVID cases in 2020 and 2021 and the need for employees and customers to interact in an office environment it became necessary to install screens to act as a protective shield between people. These shields provided additional protection against the spreading of the virus while enabling a functioning office working environment. The most commonly used material for shields, in this case, is 3 mm and 5 mm

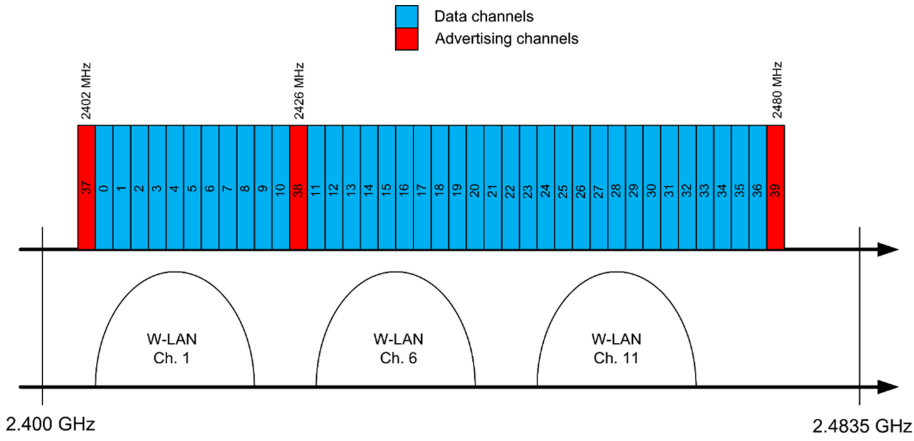

Fig. 1. Bluetooth LE channels.

Perspex as it is clear, lightweight, and easy to install. Such screens either hang from the ceilings or is installed directly on the desks or work surfaces. Bluetooth is used by various devices in an office environment and in particular for real time location. The impact of these screens on RSSI levels needed to be investigated. This led to setting up the experiment to study this impact in an office environment and report on the results.

3 Methodology

The focus of this research is to establish the received of RSSI values from Low Power Nodes when passed through obstacles, and transmitted with obstructions, and Gateways. Because Bluetooth transmission is affected by obstructions we simulate an office environment by using Perspex as screens separating workspaces. The intention is to establish the impact Perspex will have on Bluetooth transmission. The data must be derived from a reliable source thereby minimizing any error when the location is calculated. The hardware uses the latest Bluetooth technology available ie. Bluetooth 5 and the module is powered by 2 AAA batteries. The firmware has been developed to broadcast messages containing the device UUID and the message identifier at regular intervals. The research entails the setup of the hardware, setup of the screens, and capture of data from LPN's to a server for processing.

3.1 Hardware Selection and Software Configuration

In this experiment, we used Skylab's SKB501 solution shown in Fig. 2 as the Low Power Node (LPN). This solution used Nordics NRF52840 Bluetooth® 5 System on Chip (SOC) hardware. The hardware takes uses the feature advancements of Bluetooth® 5 such as increased performance capabilities, long-range and high throughput modes.

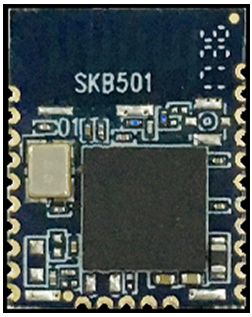

Fig. 2. SKB501 – LPN top view

The gateway setup for this experiment is a Raspberry Pi 4 with Ubuntu V18.04 as its operating system. The gateway acts as the bridge between the low power nodes and the server. BlueZ is used on the Raspberry Pi to provide support for the core Bluetooth layers and protocols. It is selected as the preferred choice as its flexible, efficient, and uses a modular implementation. The gateway software listens for broadcasts on the Bluetooth interface and translates messages to be sent to the server via the Wi-Fi network port. This application is written in C# and uses the UDP protocol to send the messages from the gateway to the server. The server is installed with the Ubuntu server as the Operating System and PostgreSQL to store the data from the low power nodes. The software to receive the message from the gateway continuously monitors for UDP messages. The software written in C# writes these messages to a data table residing in a PostgreSQL database. The LPN, gateway, and server architecture are depicted in Fig. 3.

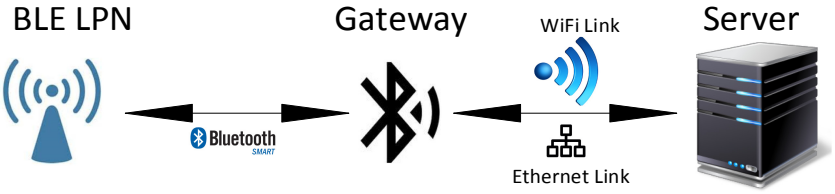

Fig. 3. Architecture

3.2 Data Collection

The LPN firmware was set up to broadcast the transmit RSSI level, LPN identifier, and unique message identifier every 100 ms. Each gateway transmitted its unique identifier. Both the gateway and LPN mac_address were initially saved so that they could be uniquely identified on the network. The unique message identifier can be used to analyze the receipt of messages at each of the gateways. This experiment simulated an office environment where workspaces are separated by partitions. In this case, we used Perspex as the partition to evaluate the impact it has on Bluetooth transmission. The obstruction

used were two sheets of Perspex measuring 1.2 m × 0.6 m × 3 mm and 1.2 m × 0.6 m × 5 mm (m = meters, mm = millimeters). The readings were observed with no obstruction, with 3 mm Perspex obstruction, 5 mm Perspex obstruction, and both 3 mm and 5 mm sheets placed side by side as the obstruction. Each test was conducted for a 5 min duration and this was repeated three times i.e. test 1, test 2, test 3. The tests were repeated to monitor and evaluate the consistency in the measurements taken across the tests.

The gateways labeled GW-001 to GW-004 were arranged 2 m apart at (x, y) positions (0, 2; 2, 2; 4, 1; and 6, 2). LPN001 was placed between GW-001 and GW-002 at position (1, 2) whilst LPN002 was placed between GW-003 and GW-004 at position (5, 2). This layout resulted in a 1 m distance between LPN001 and GW-001 and GW-002 and a 1 m distance between LPN002 and GW-003 and GW-004. This layout is depicted in Fig. 4. The mean RSSI values received by the gateways from the LPNs are also shown in the figure.

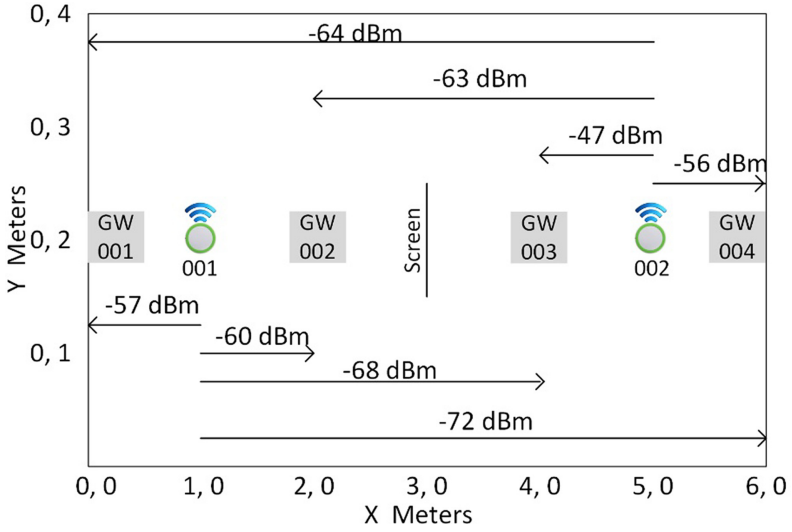

Fig. 4. LPN and gateway layout

An application was used to configure the positions of the gateways and LPNs, set the duration of the test, and start the test. The session name and session ID (automatically generated) are used to identify the data set collected for each test. The positions of the gateways and LPNs are saved for each test. Figure 5 shows the interface for the data collection.

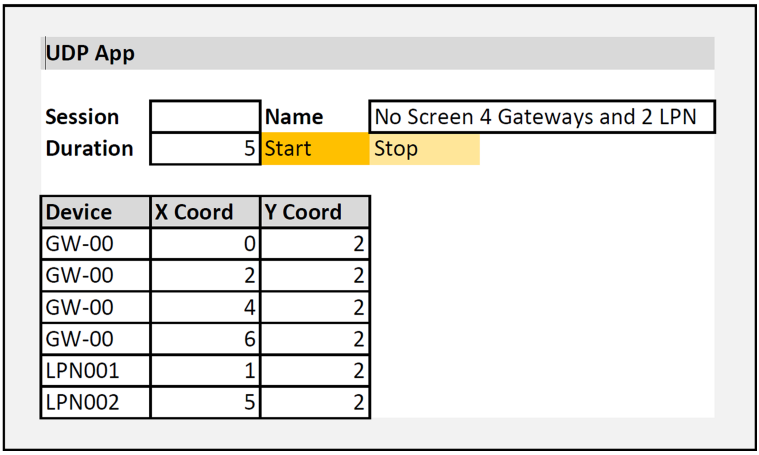

Fig. 5. UDP application for data capture

4 Results

4.1 Data Collection

An average of 28522 messages was processed by the gateways from the two LPNs over the 5 min for the tests. Each gateway processed approximately 7100 messages whilst each LPN broadcast approximately 300 messages. All details of the test, messages and locations of the gateways and LPNs were saved to the PostgreSQL database.

4.2 Aggregation of Data

After analysis of the RSSI levels received and the number of messages received at each RSSI level by the gateway from each LPN, it was found that about 70% of the messages received were at 3 RSSI levels as depicted in column "J" in Table 1. Subsequent RSSI levels had significantly lower count message counts. Therefore it was decided to use the 3 RSSI levels that had the most message counts and thereafter calculate the mean which is an accepted metric for the evaluation of RSSI levels. An extract of the data received is depicted in Table 1.

An average of these three RSSI levels received by each gateway from each LPN was calculated as listed in the column "I", "Q", "Y' and "AG" in Table 2.

Table 1. Extract of data collected

	A	B	C	D	E	F	G	H	I	J
1			No Screens							
2			Test 1		Test 2		Test3		Avg	%Count
3	GW	LPN	Count	Level	Count	Level	Count	Level		295
4	GW-001	LPN001	85	-60	111	-59	110	-59	-57	75
5	GW-001	LPN001	73	-55	81	-55	86	-55		92
6	GW-001	LPN001	62	-58	78	-58	57	-58		86
7	GW-001	LPN002	83	-64	97	-64	86	-64	-64	68
8	GW-001	LPN002	65	-60	55	-61	65	-67		69
9	GW-001	LPN002	52	-67	52	-67	52	-61		69
10	GW-002	LPN001	98	-56	102	-56	87	-56	-60	73
11	GW-002	LPN001	61	-70	62	-54	80	-54		68
12	GW-002	LPN001	55	-54	37	-69	48	-69		73

Table 2. Aggregated data

	A	B	I	Q	Y	AG
1			No Screens	3 mm Screen	5 mm Screen	3 and 5 mm Screen
2			Avg	Avg	Avg	Avg
3	GW	LPN				
4	GW-001	LPN001	-57	-57	-57	-56
5	GW-001	LPN001				
6	GW-001	LPN001				
7	GW-001	LPN002	-64	-64	-61	-64
8	GW-001	LPN002				
9	GW-001	LPN002				
10	GW-002	LPN001	-60	-57	-57	-58
11	GW-002	LPN001				
12	GW-002	LPN001				
13	GW-002	LPN002	-63	-63	-63	-62
14	GW-002	LPN002				
15	GW-002	LPN002				
16	GW-003	LPN001	-68	-68	-68	-69
17	GW-003	LPN001				
18	GW-003	LPN001				
19	GW-003	LPN002	-47	-47	-47	-47
20	GW-003	LPN002				
21	GW-003	LPN002				
22	GW-004	LPN001	-72	-71	-74	-73
23	GW-004	LPN001				
24	GW-004	LPN001				
25	GW-004	LPN002	-56	-62	-56	-56
26	GW-004	LPN002				
27	GW-004	LPN002				

5 Discussion of Results

Table 2 shows the average RSSI calculated from the selected received levels. The average RSSI level is consistent across the different tests conducted for no screen, 3 mm screen, 5 mm screen, and a combination of both 3 mm and 5 mm screens. The average RSSI levels between GW-001, GW-002, and LPN001 range between −60 and −56, RSSI levels between GW-003 and LPN002 were consistent at −47, and RSSI levels between GW-004 and LPN002 range between −62 and −56. This was expected as no screens were placed between the Gateway and the LPN. However, a difference in levels was noted between the GW-003, GW-004, and LPN 4 as the distance was 1 m.

The average RSSI levels between GW-001, GW-002, and LPN002 range between −64 and −61, whilst the average RSSI levels between GW-003, GW-004, and LPN001 range between −74 and −68. No significant difference levels were noted with both the Perspex obstructions placed between GW-002 and GW-003. We can therefore conclude that 3 mm and 5 mm Perspex commonly used as COVID shields will have little or no effect on Bluetooth messages transmitted at a level of 0 dBm. Although we initially tried to determine the effect of obstructions on RSSI signals which would subsequently affect how our location determination algorithm we would proceed to take into account the results to update a footprint regularly so that they can be used for location determination.

Results show that generally the further away from the LPN the lower the level. This observation is expected as the levels drop as distance increases. These results expand on research work done by [19] where measurements were done within a meter range. Measurements of received RSSI values were recorded with and without the obstruction Perspex to establish the effect it has on Bluetooth Transmission.

6 Conclusion and Future Work

This research established the effect of using Perspex as an obstruction on Bluetooth signals between LPNs and Gateways. Using 4 Gateways, 2 LPNs, 3 mm and 5 mm Perspex the experiment was conducted in a 6 m by 4 m office. In general, the 3 mm and 5 mm Perspex did not have a significant impact on the Bluetooth signal. Although these results were not as expected these are experimental results. Our concern is to obtain the RSSI signal strength for accurate location determination taking into account a specific common indoor scenario, i.e. office environment where Perspex is used as a screen/partition that could lower the signal strength. Our work indicates that BLE signals are not affected by these common obstacles and the RSSI levels can be used for location determination.

Future research will include establishing and testing an increased number of LPNs and Gateways in the same environment. Another variation that will be tested is to set up screens to cover a wider width and then test the impact of the screens on the transmission between the LPNs and the gateways to determine if obstacles do play a part in RSSI signal strength transmission, which is relied upon for location determination. We started our experiment with the most common obstacle, Perspex, and are moving to less common but frequently found items like metal cabinets and shelving. The findings of this future research will be presented in subsequent articles.

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