Obstruction-aware Bluetooth Low Energy Indoor Positioning

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BIOGRAPHIES

Arief Juri is a PhD candidate at the University of Edinburgh. He is currently doing research in the area of indoor positioning system, specifically using Bluetooth Low Energy. He received his MSc from University Malaysia Perlis with a dissertation on Low Power H.264 Video Compression. His prior education is Microelectronic bachelor degree, also from University Malaysia Perlis.

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Professor Tughrul Arslan holds the Chair of Integrated Electronic Systems in the School of Engineering, University of Edinburgh, Edinburgh, U.K. He is a member of the Integrated Micro and Nano Systems (IMNS) Institute and leads the embedded and wireless sensor systems group in the University. His current research focuses on enhancing personal mobility and the design of high performance embedded wireless sensors based systems. Professor Arslan was an Associate Editor for the IEEE Transactions on Circuits and systems I and IEEE Transactions on Circuits and Systems II. He is a member of the IEEE CAS Committee on VLSI Systems and Applications and is involved in the organisation of numerous conferences.

ABSTRACT

Bluetooth low energy (BLE) technology is demonstrating significant potential in providing accurate and reliable positioning indoors. However, wireless signals such as Bluetooth, tend to be affected by an obstruction, thus creating a non-line-of-sight (NLOS) environment.

This paper proposes a statistical technique for improving the accuracy of indoor positioning using BLE technology through detecting obstructions and compensating for signal degradation caused. Several experiments are conducted to observe the obstruction effect on the signal stability, computed in this paper using standard deviation. Results show a lower standard deviation for an NLOS environment. A threshold is suggested at 2.6 dBm to detect a line-of-sight (LOS) environment. The detection accuracy of this threshold is 76.25%; thus, in most cases, the technique will be able to differentiate an LOS from an NLOS environment. Using this technique, positioning in NLOS environments show an average of 1.13 metres improvement compared to positioning without using the technique.

INTRODUCTION

Location-based services have experienced exceptional growth over the past decade. The increased variety of location-based services has triggered an increasing demand for indoor positioning services. However, the global positioning system (GPS) does not function indoors due to the requirement for line-of-sight (LOS) to the satellite; thus, indoor positioning would require alternative wireless technologies to identify a user's location [1]. Major signals used for indoor positioning are augmented GPS [2], cell phone localisation [3][4], Radio-Frequency Identification (RFID) tags [5][6], Wi-Fi [7][8], and Bluetooth [9][10]. Some of these signals have low accuracy while others are expensive to deploy, and some have a laborious calibration process. Therefore, a compromise is required for the chosen signal depending on the requirements [11]. For this paper, Bluetooth signal is chosen, as it shows high accuracy with low cost. Moreover, Bluetooth low energy (BLE) beacons specialised for indoor positioning promise long battery life and low maintenance, thus becoming a wireless technology of choice, especially for retailers [12].

There are several techniques to determine the distance using wireless signals, namely time of signal arrival (TOA), angle of arrival (AOA), time difference of arrival (TDOA), and received signal strength (RSS) [13]. In some papers, RSS is interchangeable with Received Signal Strength Indicator (RSSI). Moreover, RSS tends to be a chosen technique for most because it does not require any additional hardware for its implementation [14]. Bluetooth uses a 2.4-GHz signal, which suffers attenuation through wall obstructions [15]. This attenuation will affect the result of the estimated distance.

A distance estimation error can be reduced by anticipating the involvement of an obstruction in the received signal. By identifying an obstruction to the signal, corresponding adjustments can be made to correct the distance estimation, thus reducing the error caused by the non-line-of-sight (NLOS) environment.

This paper proposes a technique to distinguish between LOS and NLOS environments using only RSS. First, an analysis is conducted regarding the RSS of BLE beacons in different environments to show the concept of detecting an obstruction. A sample implementation is demonstrated to prove the concept and provide improvements.

BACKGROUND LITERATURE

RSS is well-known for its instability and can be affected by numerous factors, including hardware orientation, location (environment), time and duration of measurement, radio channel interference, and human presence [16]. A test result in [16] shows that RSS standard deviation among multiple samples (between 10 and 33,000) ranges from 3.06 to 4.72 dBm.

Results in [17] display the standard deviation for obstructed and unobstructed signals. For unobstructed signals, the values range from 2.51 to 2.85 dBm. For a single wall obstruction, the values were between 2.65 and 3.13 dBm. The paper also includes results for two wall obstructions, which range from 1.96 to 2.37 dBm. No specific discussion on signal stability across wall obstruction was given and the paper also provides no differentiation between the type of walls which the signal passes. However, the results show a certain form of signal stability across an obstruction, especially through two walls.

The standard deviation of the RSS was discussed briefly in a sub-topic in [18]. The tests in [18] were conducted in two environments whose major differences were the distance and the existence of LOS between the access point (AP) and the receiver. The LOS environment is named Scenario 1 while the NLOS environment is named Scenario 2. Scenario 1 has values ranging from 0.59 to 6.29 dBm while Scenario 2 has values ranging from 0.47 to 3.30 dBm. The authors in [18] conclude that a Wi-Fi signal is more stable with low RSS and with NLOS paths.

The studies cited in this chapter utilised Wi-Fi signals as opposed to BLE signal (as employed in this paper). However, the results and the observations from the cited papers are still credible, as both signals use 2.4 GHz, indicating that they have the same wavelength and characteristics.

EXPERIMENTAL SETUP

The experiments were set up using a BLE beacon from Texas Instruments (CC2540DK-MINI) as shown in Figure 1, which displays the transmitter. A Samsung Galaxy S5 mobile phone and Samsung Galaxy K Zoom were used as BLE receivers.

The experiments were conducted in three different scenarios: LOS environment, NLOS environment with 9 cm interior hollow plasterboard obstruction, and NLOS environment with 11 cm solid concrete obstruction. Each scenario has four readings at multiple distances: 1 to 4 metres for LOS (1, 2, 3, and 4 metres), 1 to 4 metres for plywood NLOS (1, 2, 3, and 4 metres), and 1 to 2 metres for concrete NLOS (0.5, 1, 1.5, and 2 metres). Distance readings were recorded for at least 30 minutes. The transmitter, receiver, and the obstruction were set up as shown in Figure 2.

Figure 1. Bluetooth Low Energy Beacon CC2540DK-Mini.

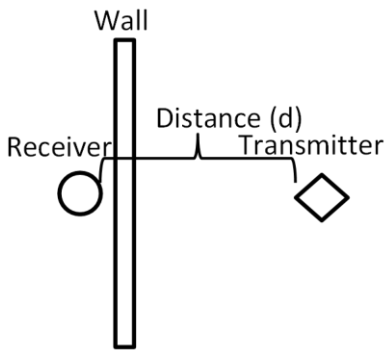


Figure 2. Bluetooth Transmitter, Receiver, and Obstruction Arrangement.

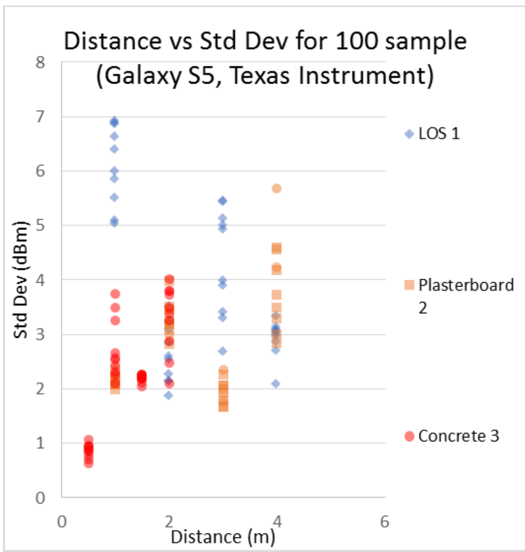


Figure 3. Distance vs. Standard Deviation (Galaxy S5).

Table 1. Accuracy for different threshold values

Std Dev Value	LOS (%)	NLOS-P (%)	NLOS-C (%)	Average (%)
2.4	87.5	50	60	65.83
2.5	87.5	50	65	67.5
2.6	82.5	50	70	67.5
2.7	82.5	50	70	67.5
2.8	77.5	50	72.5	66.67

For LOS scenario, the experiment was conducted in Scottish Microelectronic Centre portacabin, King's Building, University of Edinburgh. For NLOS plasterboard scenario, the experiment was also conducted in Scottish Microelectronic Centre portacabin, King's Building, University of Edinburgh but it were conducted across the room divider inside the portacabin. The third scenario, NLOS concrete was conducted in Faraday Building, King's Building, University of Edinburgh.

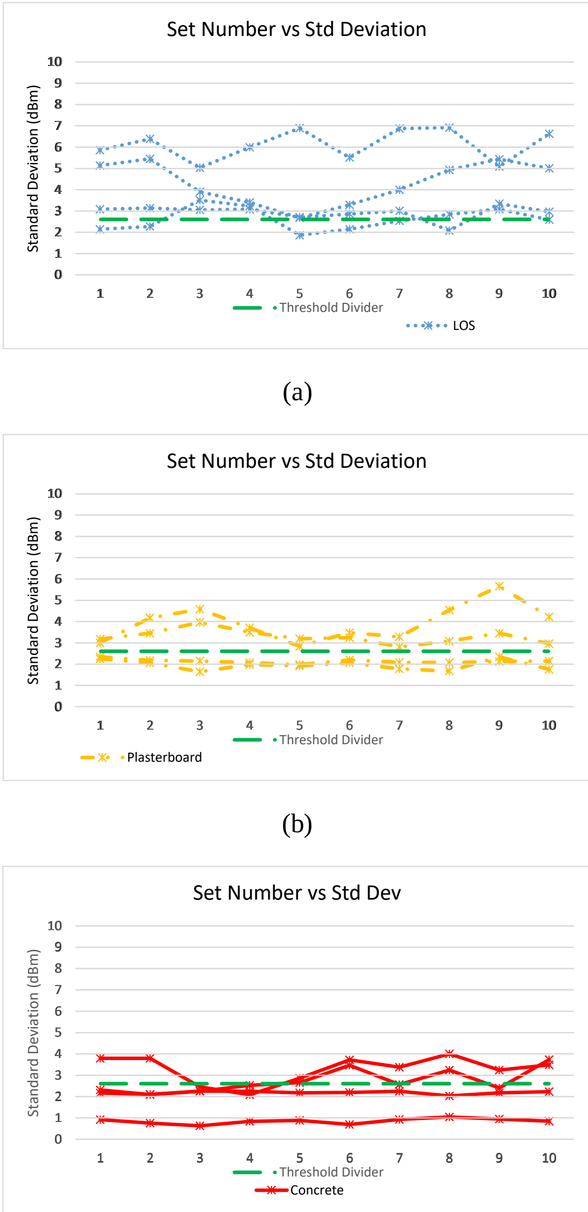
The experiments were set up in populated buildings to capture the real-world signal values. Any interference and inconsistency in the readings were recorded as well to show the real-world results and to estimate the precise expected accuracy.

RESULTS

The experimental readings were collected to identify the correlation between LOS and NLOS regarding the BLE signal. Ten sets of samples were collected for each scenario and distance, with each set containing 100 continuous RSS readings. The standard deviation was calculated for each set and used for the analysis.

Figure 3 shows the results for distance vs. standard deviation for all 10 sets of all scenarios and distances using a Galaxy S5. The graph shows that, in general, the NLOS standard deviations are lower than the LOS standard deviations with an exception at two metres. In the two-metre reading, additional interference happens, which was mainly caused by increased number of people in the room and with it, increasing the amount of 2.4 GHz signal interference due to the number of smartphones. The results also show that the standard deviation values are not affected by the distance, thus confirming that this finding is true disregarding the distance.

Table 1 shows the accuracy if several standard deviations are used to differentiate between LOS and NLOS environment. For LOS, the accuracy was calculated based on the values larger than the threshold, and for NLOS, the accuracy was calculated based on values smaller than the threshold. This difference is due to the LOS and NLOS being expected to be on the opposite side of the threshold value. The standard deviation values are chosen in between 2.4 to 2.8 dBm because outside of this range, the accuracy percentages are much lower. From the table, it can be seen that standard deviation values for 2.5, 2.6 and 2.7 dBm have the highest average. However, only one



(a)

(b)

(c)

Figure 4. Graph line for different environment scenarios in relation to the threshold (S5).

value should be used for the threshold, and the value which is the best balance between LOS and NLOS is used (2.6 dBm).

82.5% of the LOS standard deviation values ere above 2.6 dBm. Using the same standard deviation value as a reference, 70% of the concrete NLOS standard deviation values were lower than 2.6 dBm. However, for plasterboard NLOS, the values were inconsistent, as only 50% of the standard deviation values were lower than 2.6 dBm.

This representation can be clearly seen in Figure 4. Graph (a) with blue dotted lines representing the LOS covers the majority area above the green dashed line while graph (b)

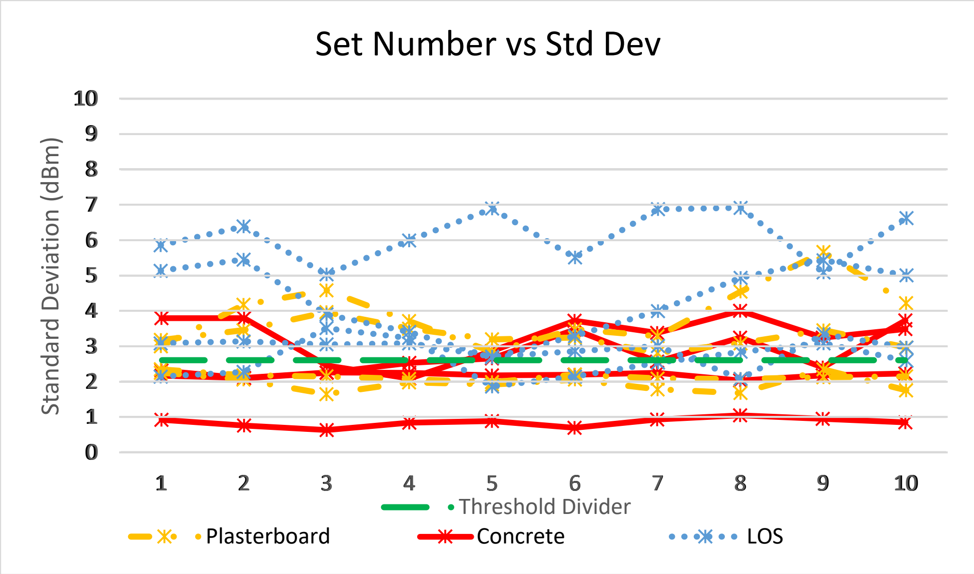


Figure 5. Set Number vs. Standard Deviation (Galaxy S5).

with solid red lines representing the concrete NLOS covers the lower majority of the green dashed line. Meanwhile, graph (c) with dashed yellow line represents the plasterboard NLOS. The green dashed line is the threshold line of 2.6 dBm. The variation in standard deviation values depicts the inconsistency in real-world BLE RSS readings.

It can be seen that the LOS and concrete NLOS show a relevant difference in differentiating the two. If 2.6 dBm is used as a threshold to differentiate between the LOS and concrete NLOS, the accuracy will be about 76.25%. However, the plasterboard NLOS shows an inconsistent result, which will affect the total accuracy to only 67.5%. The inconsistency in stability readings for plasterboard NLOS was mainly due to the hollow interior that effectively makes the total thickness of the plasterboard only 2.5 cm (1.25 cm x 2). The results show that plasterboard does affect the standard deviation value. Unfortunately, the effect was not clear enough to differentiate between plasterboard NLOS and LOS. The combination and relation between all three graphs are shown in Figure 5. Note that the actual RSS value itself is not taken into consideration to determine the difference between LOS and NLOS environment.

The same experimental method is repeated using a different phone. Figure 7 shows the results for distance vs. standard deviation for all 10 sets of all scenarios and distances using K Zoom. This result also concludes the same findings as in Figure 3, with the interference in some cases as well. The results also show that the distance has little to no effect on the standard deviation and the signal stability is mainly effected by the NLOS environment.

Figure 6 shows different environmental scenarios in relation to the threshold value. It further proves the relation between signal stability and obstructions in the environment. Identical to the results from the Galaxy S5, the difference between the LOS and concrete NLOS was easily differentiated. For the K Zoom results, 92.5% of the LOS standard deviations were above 2.6 dBm which clearly shown in Figure 6 (a). In addition, using the same standard deviation value as a reference, 72.5% of the concrete NLOS standard deviation values were lower than 2.6 dBm as shown in Figure 6 (b). However, the plasterboard NLOS standard deviation values remain inconsistent at 50% as shown in Figure 6 (c). The relationship between LOS and LOS with the selected threshold value can be seen in Figure 8.

Using 2.6 dBm as a threshold, the LOS and concrete NLOS can be differentiated with 82.5% accuracy. If plasterboard NLOS is also included to differentiate between the LOS and NLOS environment, the accuracy is reduced to 71.67%. These results were consistent with the previous results attained using the Galaxy S5, which proves that the findings are not phone specific.

The improved stability across an obstruction was due to the attenuation characteristics of a Bluetooth signal and the absorption characteristics of the material. Note that the actual values of RSS will decrease due to signal absorption. It means that while an obstruction improves the signal stability, RSS value will be decreased. In LOS environment, the RSS will be affected by reflection, which will create multipath. In the NLOS environment, the multipath will be weakened by the obstruction absorption; thus, only the direct, stronger signal remains.

IMPLEMENTATION

A positioning test was done to evaluate the efficiency of this technique. The test was executed in a well-known mall called Cameron Toll, Edinburgh, United Kingdom (EH16 5PB) [19]. This location was to ensure the test was done within a real environment. A total of seven beacons were

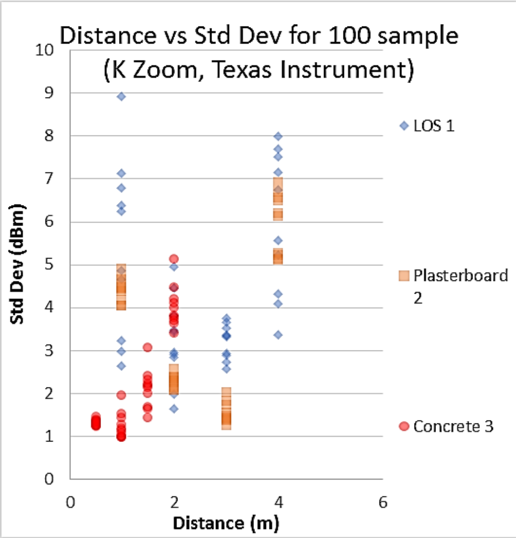


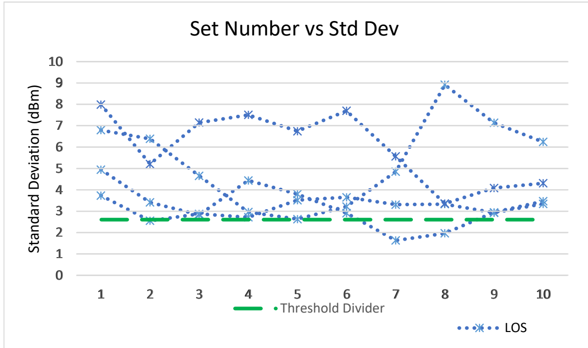
Figure 7. Distance vs. Standard Deviation (K Zoom).

used for this test. The beacons were set in the shelved area within the supermarket. The beacons and test points were set as depicted in Figure 9.

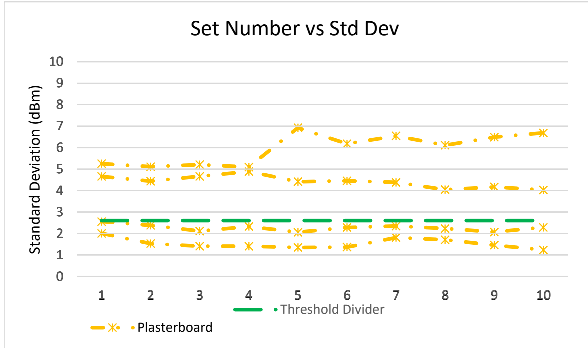
As the user's moves and objects pass through the BLE transmitter and the BLE reader. This could significantly affect signal stability. It is therefore important to shorten the time required to read the signal values. During the implementation, 8 samples were taken to calculate the standard deviation. No exact number of samples can be proposed as the time required to read the signal depends on the BLE transmitter's broadcast interval and the BLE receiver's scan interval.

Due to the obstruction effect of the shelves and the products on display, the beacons' RSS value were heavily affected. The distance was calculated based on a log-distance path loss model with different path loss exponents for different environments according to the technique. The precise value of the suitable path loss exponent is highly dependent on the material type and thickness. For this test, the path loss exponent was set to 1.8 for the LOS environments and 2.2 for the NLOS environments. To reduce human error due to manually holding the mobile device, the time required to take the RSS value should be as little as possible. For this test, only five RSS values were collected.

Figure 10 shows the implementation results. The results clearly demonstrate that the proposed obstruction detection technique does give an improvement for most of the results. There are only a few instances where the proposed algorithm performed worst. However, these are negligible. The proposed algorithm has managed to rectify errors in the base algorithm to maintain small average error, especially at test point 8, 16, 18, and 25. In general, the



(a)



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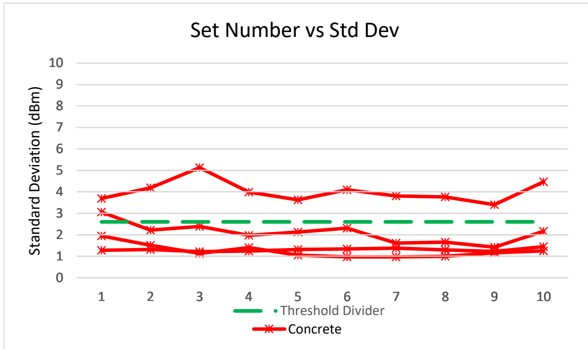

(c)

Figure 6. Graph line for different environment scenarios in relation to the threshold (K Zoom).

obstruction detection algorithm does not improve much in normal circumstances, but when there's an error introduced due to an obstruction, the algorithm is able to rectify it. On average, the positioning with obstruction-aware technique shows an improvement of 1.13 metres compared to positioning without using the technique. As RSS readings in this test were highly affected by the obstruction due to multiple items in the supermarket, the proposed obstruction detection technique does reduce the error especially when the base algorithm shows a significant error spike.

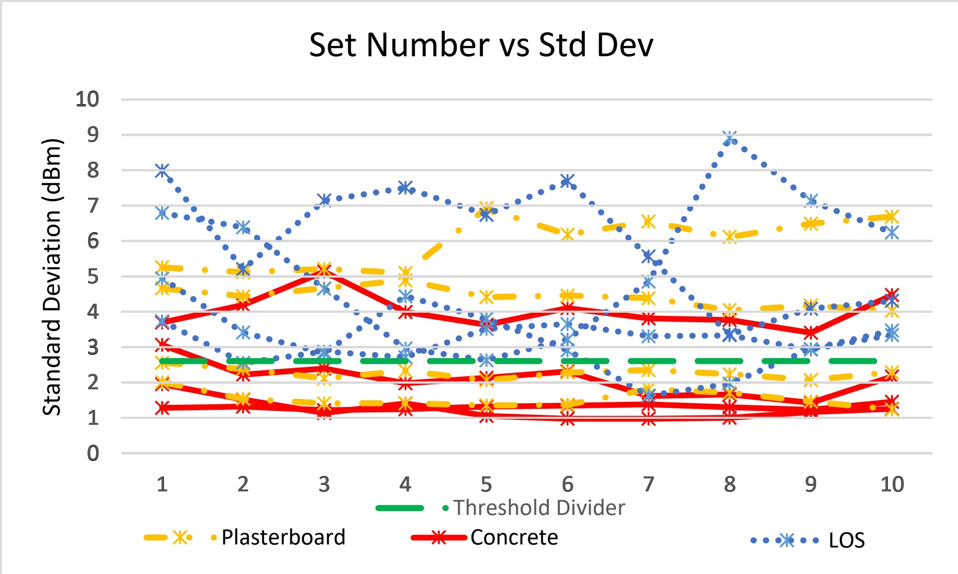

Figure 8. Set Number vs. Standard Deviation (K Zoom).

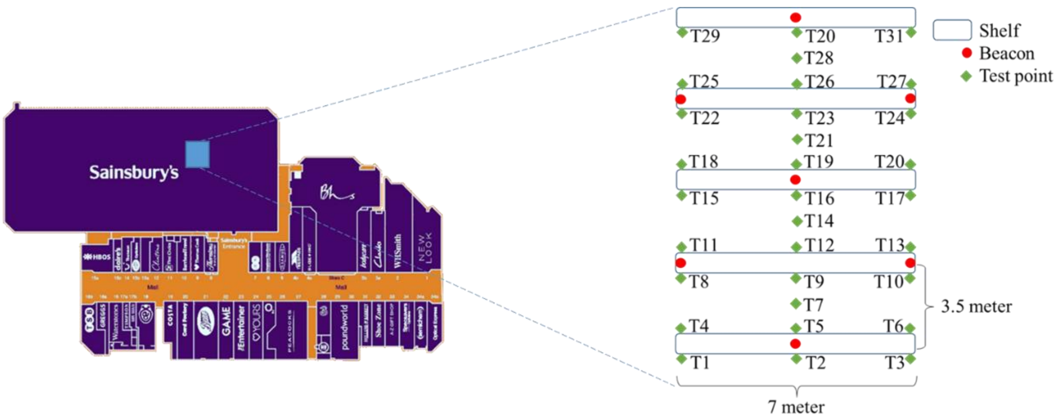

Figure 9. Beacon and Test Points Layout at Cameron Toll Shopping Mall.

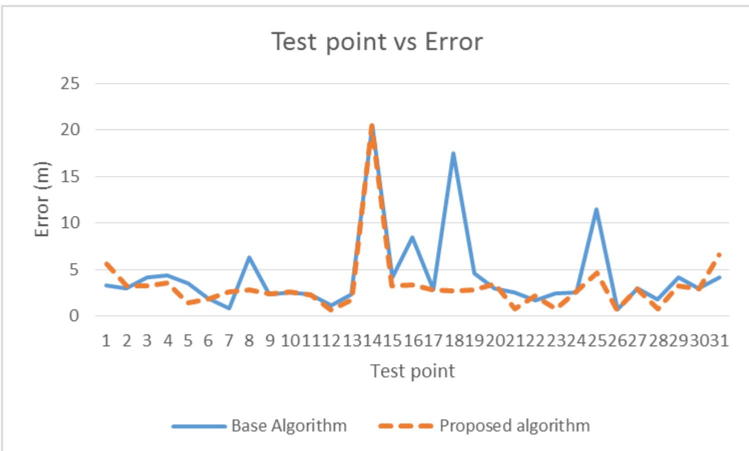

Figure 10. Error Different Between Base Algorithm vs. Proposed Algorithm

CONCLUSIONS

This paper has proposed a technique for improving positioning accuracy through compensating for obstruction in an indoor environment. Several experiments were conducted to analyse the effects of LOS and NLOS environments by monitoring signal stability using a parameter such as standard deviation. The results show a difference between LOS and NLOS environments. Even with different devices, the same findings remain true, thus indicating the consistency of the technique.

A standard deviation of 2.6 dBm is recommended as the threshold value to differentiate between the LOS and NLOS environments. With this threshold value, the accuracy obtained is 76.25%. Unfortunately, this accuracy is only applicable to differentiating the LOS with concrete NLOS.

An implementation test was done using the proposed technique, and the distance was calculated using the log-distance path loss model with different path loss exponents for different environments. The test shows that by implementing the proposed obstruction-detection technique, results will be improved especially when error spikes happen. The results also display an average of 1.13 metres improvement compared to positioning without using the technique.

This paper proves that it is possible to identify LOS and NLOS environments using RSS based on standard deviation. By differentiating the environment, it will help to reduce errors caused by NLOS.

Further experiments and analysis will be conducted for multiple venues with different materials used for obstructions. Different obstruction dimension will also be utilised in the final paper.

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