Check for updates

Distance Estimation Using Low Calibrated Tx in BLE'S Advertising Mode for COVID-19 Contact Tracing

Thein Oak Kyaw Zaw[1](✉), Saravanan Muthaiyah[1], Byeonghwa Park[2], and Muhammad Afif Bin Mohd Fathullah[1]

[1] Faculty of Management, Multimedia University, Cyberjaya 63100, Malaysia
rahman93.iu@gmail.com
[2] Kean University, Newark 07083, NJ, USA

Abstract. The ability to estimate distance between people has been an important aspect in contact tracing especially in this Covid-19 pandemic. This is because, distance is one of the crucial element in determining whether a person is a close contact or not. In this context, Centers for Disease Control (CDC) and Prevention has provided a guideline to be followed, which is the distance of no more than 6-feet (~2 m) to be accepted as close contact. With regards to that, many of the solutions in existence are adopting Received Signal Strength Indicator (RSSI) in Bluetooth Low Energy's (BLE) connected mode to determine distance. However, the mainstream approach has two main setbacks and they are: (1) Unreliable real-life implementations and (2) Ability to cater for limited number of users which makes it unscalable. Thus, in providing some closure, our study proposed using low calibrated Transmission Power, Tx, in BLE advertising mode for indoor scene, to effectively conduct distance estimation for the pandemic. Results obtained have shown that our proposed solution has a maximum error of 0.3209m in distance estimation within the distance of 2 m. Contributions of this study is two-fold: (1) It provides a novel approach in estimating distance using BLE's RSSI in the advertising mode utilising low calibrated Tx and (2) The proposed solution eliminates limited number of users that makes it scalable.

Keywords: Bluetooth Low Energy · Distance Estimation · Transmission Power · Received Signal Strength · Contact Tracing · COVID-19

1 Introduction

COVID-19 is a highly infectious virus that has become a pandemic in a short period of time. It had emerged back in 2019 and has severely affected many health systems worldwide [1]. The pandemic effects not just the people's health but many aspects of human life as well, including manufacturing, businesses, tourism and many more [2]. With that being said, contact tracing becomes a crucial measure to manage and break the chains of spread for the pandemic [3]. Contact tracing in general, is the activity to identify the close contacts with an infected person. While for close contact, it means a

© The Author(s) 2022
A. Asmawi (Ed.): ICTIM 2022, AEBMR 228, pp. 68–75, 2022.
https://doi.org/10.2991/978-94-6463-080-0_6

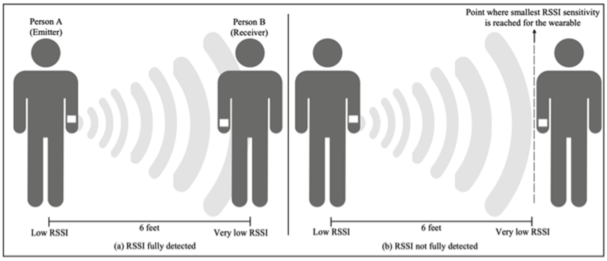

Fig. 1. (a) RSSI fully detected; (b) RSSI not fully detected

person who had a face-to-face contact within a stipulated distance with a positive patient [4]. In this context, CDC has lay down guideline to be followed for the distance in order to be considered as one.

Even though the guidelines is not fixed as there are many variants of COVID-19 virus, it provide general rules to be followed. The guideline is the distance of no more than 6-feet (~2 m) from one another and duration of no less than 15-min period [5]. With the conditions set, distance estimation becomes an important aspect and it is mainly obtained using RSSI in Bluetooth-based contact tracing solutions [6]. However, many studies have shown that using RSSI in distance estimation is unreliable [7]. On the other hand, Tx in the BLE can calibrated to suit a condition' needs. Using this insight, our proposed solution utilises low calibrated Tx in BLE to conduct distance estimation. The theory behind it is that usage of low Tx will make the RSSI to be small as the signal produced is weak. While so, Tx is calibrated so that after the distance of 2 m, the signal cannot be fully captured anymore.

This is because, the maximum RRSI sensitivity for the BLE chipset has been reached at that distance. While so, BLE chipset is set in advertising mode that requires no handshake between the devices. Thus, it is able to be utilised for a large group of users making it scalable. In return, the approach makes the distance estimation to be more reliable and accurate as: (1) Maximum distance has been set making it less prone to surrounding errors, (2) Physical obstacles will not have much of an affect as the distance is small. Figure 1 shows the proposed method used. Contribution from this study will be a novel approach on distance estimation using low calibrated Tx in BLE emphasising on COVID-19 pandemic. The approach also can be utilised for other similar outbreaks in existence or to come. While so, implication will be better pandemic management if the approach can be adopted in the contact tracing solutions.

2 Method

In this study, inputs from two nRF52832 System on chip (SoC) powered by 5V lithium-ion battery were taken in order to determine the RSSI readings at various distances in line-of-sight (LOS). Two devices were used as it will ensure that if any variations occur, they will be detected. The specifications of the BLE chipset with a central processing unit (CPU) of 64 MHz Arm Cortex-M4 with flash memory of 256kb along with a 128KB random access memory (RAM) and armed with a maximum Tx of 4dBm. These

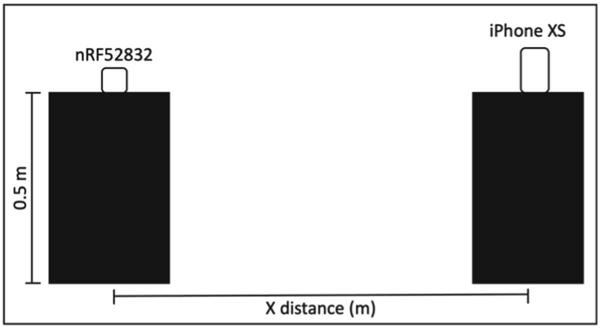

Fig. 2. Experiment Set Up

No.	Mac	RSSI	Date
1	ac:23:3f:a5:74:34	-58	2022-02-22 08:19:59
2	ac:23:3f:a5:74:34	-58	2022-02-22 08:19:54
3	ac:23:3f:a5:73:bc	-59	2022-02-22 08:19:49
4	ac:23:3f:a5:74:63	-81	2022-02-22 08:19:44
5	ac:23:3f:a5:73:e8	-67	2022-02-22 08:19:39
6	ac:23:3f:a5:74:34	-63	2022-02-22 08:19:33
7	ac:23:3f:a5:74:63	-81	2022-02-22 08:19:27

Fig. 3. Sample of Captured Data

specifications make the BLE chipset more than satisfactory to be used in this experiment to test the low calibrated Tx approach. Tx in this study was set at -8 dBm in which, it is the best suited value for the scenario as the RSSI is reaching towards -96 dBm at the distance of 2 m which is the maximum sensitivity for nRF52832. The study was conducted with 100 observations in initial stage so that the data could be considered adequate and reliable. The equipment that used to capture the data from the generated data packets by the two devices was an iPhone XS with an iOS15.1 operating system. These data were then transformed and tabulated into Excel Sheets. Captured data has four main information and they are: (1) Medium Access Control Address (Mac address), (2) RSSI value, (3) Date and (4) Time.

It should be noted that, the experiment was administered in a controlled environment where no other network connectivity (mobile phone was kept in aeroplane mode) nor interference were present. Furthermore, during the experiment both sender and receiver were in a direct angle and elevated to 0.5m as to imitate actual wearing of wearables on the wrist. Figure 2 illustrates the experiment set up and Fig. 3 shows sample of captured data from Excel sheet.

2.1 RSSI Reference Value

This initial part of experimentation is to determine average reference RSSI value, $RSSI_r$, at a point in which, is set at 1m for Bluetooth applications [8]. Furthermore, it was also

Table 1. Results for RSSI Measurement for Three Different Distances using Two Devices Under Line-Of-Sight Condition

Device Number, *n*	**Condition**	Distance, m	Observations	Max Value, $RSSI_{max}$	Min Value, $RSSI_{min}$	Average Value, $RSSI_{avg}$
1	No obstacle – Line of sight	0	100	-39	-33	-35
2				-37	-32	-35
1		1		-78	-66	-71
2				-75	-70	-72
1		2		-90	-77	-83
2				-86	-78	-82

set this way as to monitor the maximum limit of RSSI value at the distance of 2m for the selected transmitted power. The average reading taken at a distance of 1m is chosen as the $RSSI_{r,}$ this is as currently there have been no material on factory calibrated RSSI reference point for the hardware used in this experiment. Table 1 shows the result from the initial part of the experiment. From the results in Table 1, it shows that at a distance of 0m, the average RSSI reading are at -35dBm for both devices. This was also the case detected for the other two distances as well, though there was a slight deviation of value for the distance of 1m. However, it does not translate to unreliability of the data collected as it was not a significant deviation as the difference was only -1dBm. While so, average maximum RSSI value of -83 dBm and -82 dBm were obtained from both devices at the distance of 2 m in which, the initial will be the maximum value to be used for distance estimation.

Any value that is greater than that will suggest that another user is in the distance of more than 2 m. Thus, in estimating distance between two devices, -72 dBm will be used as the constant $RSSI_r$. It should be noted that the value will not change even though there maybe errors or inconsistencies that may arise further in the development. This is as, it is a constant used in determining distance for the sensors and specifications that have been used. As such, what matters is not the value at 1m, but instead that the observed values should be closing on to the maximum RSSI value of -96 dBm for nRF50832 chipset at the distance of 2 m. Tx was specified to -8 dBm in this experiment as it was detected that the RSSI is closing to its maximum sensitivity for nRF5083 at 2 m even though it has not reached yet fully. The observed RSSI at 2m, which is $RSSI_{avg,max}$, is at -83 dBm and the difference for the maximum sensitivity is to offset the instability that is associated with RSSI especially from physical obstructions.

2.2 Distance Estimation Formula

This study has used Eq. (1) to calculate distance estimation following the study administered by [9]. $RSSI_r$ is the reference distance at 1m and $RSSI_i$ is the RSSI value at the distance i. Equation (1) was used in this study though there were a few other equations that can be chosen as it was examined to be the best fit option for the approach used in this study. This is because, as Tx was set to low and calibrated, elements such as signal propagation loss or paths loss model will not be relevant. Furthermore, the value of $RSSI_r$ has already been acquired, thus the only thing that matters now is to discover the value of n, which is the environmental factor constant with range of 2 - 4. The value n is also known as attenuation factor.

The constant factor is set that value 4 is considered to have the highest in strength while on the other hand value 2 is considered to have the weakest in strength.If a solution is meant to be used in an outdoor-mode, value of close to 2 can be utilised. While for indoor-type of environment, value range from 3 to 4 are commonly used.

$$Distance = 10^{\frac{RSSI_i - RSSI_r}{10n}} \tag{1}$$

For this study, n with the value of 3.5 was chosen due to several reasons. The first, is that because the study will be in an indoor-type environment in which the space will be enclosed by walls. The second reason is that by using low Tx, it creates strong signal attenuation which will make the value to be high. Thus, there will be strong attenuation associated with it. The BLE chipset of nRF52832 only has maximum sensitivity of -96 dBm in which, it will be reaching the maximum value when users go little bit further than 2 m. Thus, it will require a strong n-value to compensate it in the distance calculation. Therefore, after taking all these factors into consideration, n value of 3.5 will be chosen for this study as it fulfils the requirements needed and matches the average maximum RSSI, $RSSI_{avg,max}$ to be set at 2m.

3 Results

With the experimentation has been set and variables in distance estimation formula obtained, Table 2 show the results from the distance estimation experimentation.

In general, n with values 3.5 shows that it has been able to calculate distance in quite effective manner with solution's biggest potential distance estimation error under optimum condition is to be at **0.3209m** with an average error of **0.111m**. Not just that, the result also shows that the obtained value can be lesser than the actual distance. However, the difference is small that it will not have much of an effect. Therefore, as a conclusion, the value n = 3.5 is proven to be a good value in estimating distance. Not just that, using the low calibrated Tx approach gives on par estimation with other BLE based contact tracing solutions for distance estimation. For example, [9] using multiple Bluetooth beacons is getting proximity error of 0.27m in distance of 3m. [10] on the other hand, uses 19 beacons in a 600m2 environment and able to achieve error of 2.6m. While so, it can be set that after the distance of 2 m or the value of more than -83dBm, the distance estimation is no longer accurate as the RSSI is too small reaching the maximum.

Table 2. Results of Calculated Distance using Distance Estimation Formula

Device Number, *n*	Condition	Actual Distance Distance, d_a	Observations	Average RSSI, $RSSI_{avg}$	Calculated Distance, d_c	Difference, d_c - d_a
1	No obstacle – Line of sight	0	100	-35	0.087m	0.087m
2						
1		0.3		-49	0.220m	0.02m
2						
1		0.5		-68	0.7686m	0.2686m
2				-69	0.8209m	**0.3209m**
1		1		-72	1m	0
2						
1		1.5		-77	1.3895m	-0.1105m
2				-80	1.6927m	0.1927m
1		1.8		-79	1.5848m	-0.2152m
2				-80	1.6927m	-0.1073m
1		2		-83	2.062m	0.062m
2						
				Average		0.111m
1		2.3		-84	2.202m	-0.098m
2				-85	2.3520	0.052m

4 Conclusion

From the study conducted, it has been proven that the approach is good and accurate in estimating distance especially for COVID-19 pandemic. While so, it can also be used to for similar future pandemics to come by adjusting the Tx to suit the condition' needs. Apart from that, there are always rooms for improvements such as more distance testing and addition of more conditions in making it more solid. Nevertheless, this novel approach has the potential to be the next main stream distance estimation method for contact tracing and other applications as it eliminates the current setbacks in the status quo solutions. The main setbacks will be that it will be hard to implemented on mobile-based BLE solutions as differentt devices has different requirements to receive and send the advertising packets.

Acknowledgments. This work is supported by Faculty of Management (FOM), Multimedia University, Cyberjaya, Malaysia.

Authors' Contributions. The main author responsible for the investigation process, writing of the original draft, methodology selection, and formal analysis of the study. Co-author 1 was responsible for the conceptualization of the study ideas, assisting in the investigation process, validation of the study and supervising the main author. Co-author 2 was responsible for the review and editing of the paper and assisting in the formal analysis of the study. Co-author 3 was responsible for the visualization of the paper.

References

1. M. Nicola et al., "The socio-economic implications of the coronavirus pandemic (COVID-19): A review", International Journal of Surgery, vol. 78, pp. 185–193, 2020. Available: https://doi.org/10.1016/j.ijsu.2020.04.018.
2. World Health Organization, "Coronavirus disease (COVID-19) – World Health Organization", Who.int, 2022. [Online]. Available: https://www.who.int/emergencies/diseases/novel-coronavirus-2019. [Accessed: 12- Apr- 2022]
3. J. Hellewell et al., "Feasibility of controlling COVID-19 outbreaks by isolation of cases and contacts", The Lancet Global Health, vol. 8, no. 4, pp. e488-e496, 2020. Available: https://doi.org/10.1016/s2214-109x(20)30074-7.
4. H. Cheng, S. Jian, D. Liu, T. Ng, W. Huang and H. Lin, "Contact Tracing Assessment of COVID-19 Transmission Dynamics in Taiwan and Risk at Different Exposure Periods Before and After Symptom Onset", JAMA Internal Medicine, vol. 180, no. 9, p. 1156, 2020. Available: https://doi.org/10.1001/jamainternmed.2020.2020.
5. Health departments, "Contact Tracing for COVID-19", Covid-19, 2022. [Online]. Available: https://www.cdc.gov/coronavirus/2019-ncov/php/contact-tracing/contact-tracing-plan/contact-tracing.html. [Accessed: 12- Apr- 2022]
6. Prottay Kanti Roy and R. Kumar, "Accurate Estimation of Bluetooth RSSI and Distance", International Journal of Engineering Research and, vol. 5, no. 03, 2016. Available: https://doi.org/10.17577/ijertv5is030130.
7. A. Kwiecień, M. Maćkowski, M. Kojder and M. Manczyk, "Reliability of Bluetooth Smart Technology for Indoor Localization System", International Conference on Computer Networks, pp. 444–454, 2015. Available: https://doi.org/10.1007/978-3-319-19419-6_42 [Accessed 13 April 2022].
8. L. Maccari and V. Cagno, "Do we need a contact tracing app?", Computer Communications, vol. 166, pp. 9–18, 2021. Available: https://doi.org/10.1016/j.comcom.2020.11.007.
9. A. Mackey, P. Spachos, L. Song and K. Plataniotis, "Improving BLE Beacon Proximity Estimation Accuracy Through Bayesian Filtering", IEEE Internet of Things Journal, vol. 7, no. 4, pp. 3160–3169, 2020. Available: https://doi.org/10.1109/jiot.2020.2965583.
10. R. Faragher and R. Harle, "Location Fingerprinting With Bluetooth Low Energy Beacons", IEEE Journal on Selected Areas in Communications, vol. 33, no. 11, pp. 2418–2428, 2015. Available: https://doi.org/10.1109/jsac.2015.2430281.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.