Minimizing Discovery Time in Bluetooth Networks Using Localization Techniques

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Abstract- **Bluetooth is a short range wireless communication protocol. However, the discovery process to establish connection in Bluetooth network is very time consuming process. This paper presents localization techniques for Bluetooth networks. There is an increasing interest in location identification, and communication with other Bluetooth devices within a local area network. The idea behind localization techniques is to address position estimation in Bluetooth networks in order to reduce the time taken for device discovery to establish connection process. In this paper Received Signal Strength Indicator (RSSI) is obtained using Inverse square law. The Received Power (Prx) is obtained indirectly by converting RSSI values to Prx using Friis equation. Positioning is based on Prx and converted to estimate the distance using simple radio propagation model based on Friis equation. The advantage of positioning is to know the object actual position with respect to the distance from the transmitter. The relationship obtained from positioning using Prx will be used to minimize the discovery time in connection establishment process in Bluetooth networks. This work is part of the design process of roaming protocol for Bluetooth networks.**

Keywords- component, Bluetooth, Localization, RSSI, Roaming.

I. INTRODUCTION

BLUETOOTH is a short range wireless radio technology that enables Bluetooth enabled electrical devices to wirelessly communicate in the 2.45 GHz ISM (license free) frequency band [1]. The communication changes the transmitting and receiving frequency 1600 times per second, using 79 different frequencies. The range of Bluetooth network can be 0 to 100 meters. It is used to transmit both synchronous as well as asynchronous data. The bandwidth of the Bluetooth network at physical layer is 2.1 mb/s [2].

Localization refers to fin1ding the position of an object, node or any mobile device which have a wireless link with reference to some known points. Bluetooth is a short range communication protocol. This is mostly used for Wireless Local Area Network (WLAN). Therefore positioning in Bluetooth is similar to Wireless Local Area Network Platform [5]. Localization techniques for Bluetooth networks can be broadly categorized in two types [5].

A. Dedicated systems can provide the high rate of accuracy but the equipments required for dedicated systems are very expensive and energy consuming. In this paper only the non dedicated techniques are selected.

B. And non dedicated localization techniques. These techniques use non dedicated systems.

Currently, Bluetooth does not support any roaming protocol in which handoff occurs dynamically when a Bluetooth device is moving out of the piconet. A localization technique is one of the techniques used to handle this problem, the purpose of selecting an efficient positioning technique which, will be based on Received Signal Strength Indicator and its relation with distance. The purpose of localization is to reduce discovery time for Bluetooth devices, which are going out of range and connecting with other master. The advantage of selecting the localization technique for roaming issue is to reduce connection establishment time and hand over process.

The remainder of this paper is structured as follows. Section II, discusses Localization techniques for Bluetooth networks. Section III discusses RSSI and Received Power level. Section IV discusses proposed distance estimation algorithm and finally conclusion and future work discussed in section V.

II. LOCALIZATION TECHNIQUES

There are various localization techniques proposed by various researchers. In [5], a survey or wireless geolocation techniques has been presented. In [6], a comparative study of various RSS collaborative localization techniques adopted for wireless sensor networks has been discussed. These techniques are used to locate the position of the incoming signal. On the basis of these techniques distance estimation algorithm will be selected for Bluetooth networks, which have the lowest deployment cost and high accuracy ratio.

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A. Global Position System (GPS)

GPS is one of the most well known navigation system, which is used for tracking the object position. Three things are required to fix the position of object using GPS. The reciveing device which have the GPS capability. The trasmitter actually the sattellites which broadcast signals and the medium which is used for communication. These satellites move around the earth twice a day in a specific orbit and transmit signal information to GPS controller on earth. GPS receivers use these information and with the help of triangulation and calculate the user's exact location. Actually, the GPS controller on earth compares the timing of the signal [3]. It calculates both the transmission time and received time and then calculates exact position of the mobile object. The difference between their timing tells about how far away it is from the source. The software installed on the receiver side then calculates its three dimensional position from the electronic map

Positioning of the mobile device is fixed from satellites which consist of 24 satellites [13]. These satellites broadcast signals from space that are captured and identified by the receiver. Each GPS receiver then provides the three dimensional position of the mobile object [3].

B. Angle of Arrival (AOA)

In this section, AOA is discussed which is used to determine the direction of a signal which is received by the antenna. So, finding the angle between propagation direction and reference direction gives us AOA. The incident angel is determined. This technique requires array of antennas in some specific direction. The number of antennas leads to the accuracy of the incident angel [6], [7]. Fig. 1[6], shows the scenario for AOA, which have one receiver and three transmitters. Angle at which the signal is incident at the receiver is measured and on the basis of these angles the distance to the object is estimated.

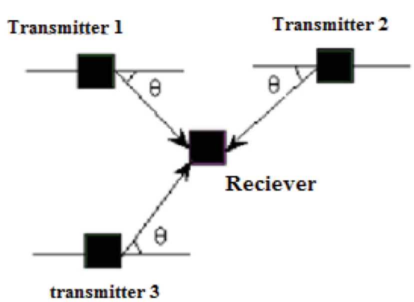


Figure 1. : Angle of Arrival

The angle-of-arrival technique can be categorized into two subcategories: [12] those making use of the receiver antenna's amplitude response and those making use of the receiver antenna's phase response.

C. Time of Arrival (TOA)

This technique is based on the time measurements. Distance is calculated by multiplying the propagation time with the speed of air. The delay in time when the signal arrives to the signal transmitted by the transmitter give us the distance estimate. GPS use TOA technique. Fig. 2 [6] shows TOA, technique for localization, in which the receiver measures the timing for the signals received and the distance is estimated using time of propagation [6].

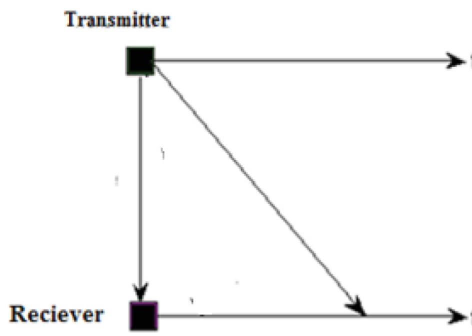


Figure 2. Fig. 2: Time of Arrival

D. Time Difference of Arrival (TDOA)

Fig. 3 [6], shows TDOA localization technique. In this technique the difference between the signals received to the signal transmitted is calculated. This technique eliminates the tight synchronization of the AOA. This technique requires the accurate timing synchronization, which leads to the high position estimation accuracy. Distance is calculated by multiply the propagation time with the speed (v). This process is carried out for multiple signals arrived at different time of interval. The calculation of distance from the transmitter can also be calculated by using the technique triangulation or trilitration. Due to the accurate time synchronization required, this technique is rarely used in Bluetooth short range networks, because Bluetooth is the low cost personal area network.

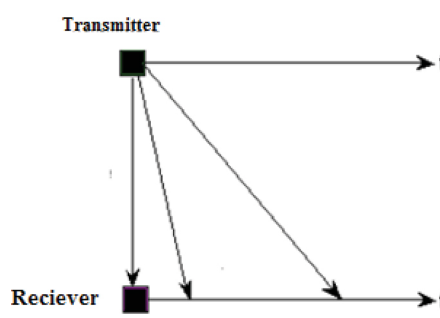


Figure 3. Time Difference of Arrival (TDoA)

In this Method the time is compared among different receivers like to locate the mobile unit. [6]

E. Triangulation

In this technique, the angles to the unknown location, is calculated from the two known points, at either end of the fixed base line. This technique can also be combined with AOA, i.e. by measuring the direction of the arrival signals to the estimated position of the mobile device. Triangulation is a very important localization technique, which can be used for surveying, navigation, and gun direction of weapons [3]. Figure 4 [5], shows triangulation algorithm for object positioning.

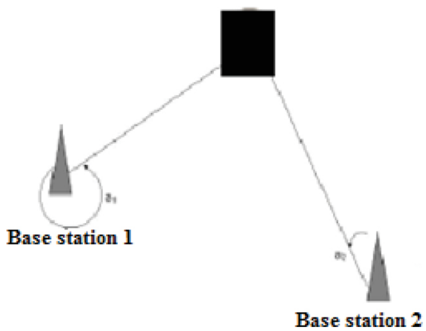


Figure 4. Triangulation: Estimation of distance between the receiver and the transmitter or base station using AOA.

With the help of trigonometry we can find the angels to the receiving device using the following equations. Alpha α and Beta β are corresponding angles between the base station 1, and base station 2 and the receiving device. The distance in the following equations are taken as l, or the coordinates of base station 1 or base station 2 [3].

$$l = \frac{d}{tan\alpha} + \frac{d}{tan\beta} \qquad (1)$$

Therefore

$$d = l * \left(\frac{1}{tan\alpha} + \frac{1}{tan\beta}\right) \quad (2)$$

We can also calculate the distance to the estimate point using the law sins.

The simplified equation for triangulation using law of sins [3].

$$RC\ (d) = AB.\frac{sin\alpha.sin\beta}{\sin(\alpha+\beta)} \qquad (3)$$

Where RC = distance to the transmitter and AB= distance between base station 1 and distance between base station 2.

In short words triangulation algorithm measures the angles from the signals received from the transmitter. Some time we triangulation can be combined with other techniques such as GPS or TDOA to obtain good results in terms of accuracy.

F. Trilitration

This method is used to calculate the distance between the base station and mobile device using the trigonometric formulas. Three coordinate distance formula can be used to calculate the distance between the mobile and a base station. Three base stations are required to calculate the position of the mobile device.

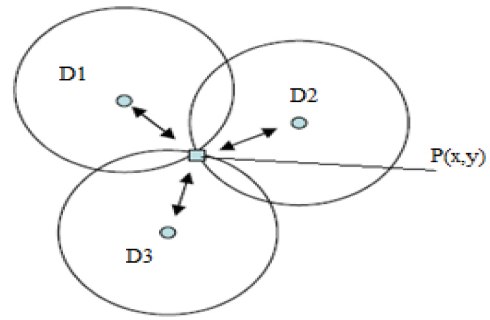


Figure 5. Trilitration: estimating the mobile device, by the intersection of three circles

The above figure 5 [5], shows Trilitration algorithm for localization which estimates the object position by intersection of three circles. Distance of the object from the center of the three circles D1, D2, and D3 is calculated using the distance formulas. So in Trilitration distance is calculated from the known positions. Table 1 summarize all localization techniques presented in this paper [5], [7],[8],[12],[13],[15].

III. RSSI AND RX POWER LEVEL

RSSI is the measure of the strength of the incoming signal. It is an 8 bit integer value. The unit for RSSI is dBm and mW. Both the units are used to measure the signal strength. The relation between mW and dBm is highlighted in equation 1 [14].

$$\text{dBm} = \log(\text{mW}) * 10. \qquad (4)$$

The distance between two Bluetooth enabled nodes can be estimated by measuring the energy level at any end [14]. Triangulation algorithm for distance estimation can also be combinly used with RSSI, if there are at least three reference nodes, whose locations are already known. This algorithm estimate the two dimensional position of the object.

Bluetooth version 1.2 provides inquiry with RSSI, which is used to discover the nearby devices. RSSI can be discovered for each Asynchronous (ACL) using HCL_Read_RSSI command. This commands returns for a specific ACL connection a signed 8 bit integer values between -128 to +127. [17]. Figure 6 shows the relation between RSSI and distance using inverse square law. According to inverse square law if you are at a specific distance from an access point and you want to measure the signal level, and then you want to move twice as far away, the signal will decrease by a factor of four. Ie when we move 2x and the signal decreases by $1/4^x$. [14]. The mathematical relation from obtained from this law is $2^x = 100/4^x$. Figure 6 is plotted in Matlab, and the result is obtained, which shows the relationship between RSSI and distance.

TABLE I. SUMMURY OF THE LOCALIZATION TECHNIQUES

Localization technique	Advantages	Disadvantages	Remarks
GPS	• Most wildly used for Object localization, for outdoor. • Applicable to all weather conditions. • Provides two, and three dimensional coordinates.	• Can't be used in indoor applications. • Requires special hardwares and softwares	(5 to 10 m) error Suitable for large scale and outdoor environment
AOA	• Localization technique • Number of anchors required for 2-D and 3-D positioning are lesser than TOA technique.	• Expensive hardware • Large no of antennas required for high accuracy • Multi path effects.	86- 12 cm (90%) Accuracy in urban areas.
TOA	• Distance estimation using signal timing • Accurate clock synchronization required.	• Accurate clock synchronization • Specialized system requirements	300m error for 1 µ sec error in timing
TDOA	• Requires at least 2 or 3 transmitter • Estimating objects through difference of arrival signals	• Accurate clock • Specialized antennas	300m error for 1 µ sec error in timing
Triangulation and Trilitration	• Estimate distance using GPS, or AoA, or TDoA.	• Accurate clock synchronization • Specialized system requirements	(5 to 10 m) (2o 5 m) error
RSSI based Position measurements	• RSSI based distance estimation is easily implemented. • Requires in expensive devices.	• No special hardware and infrastructure required	(1 to 5 m) error Proposed distance estimation technique

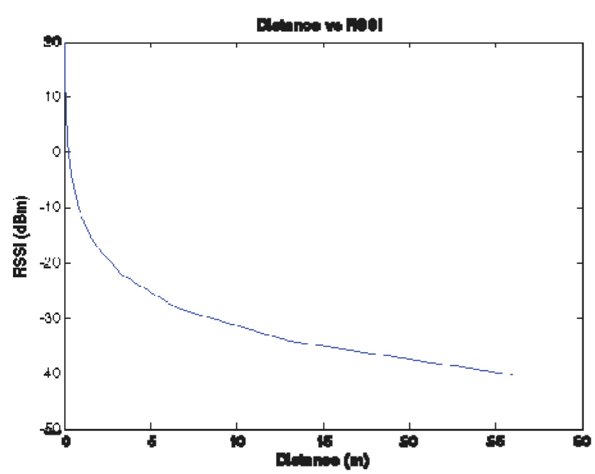
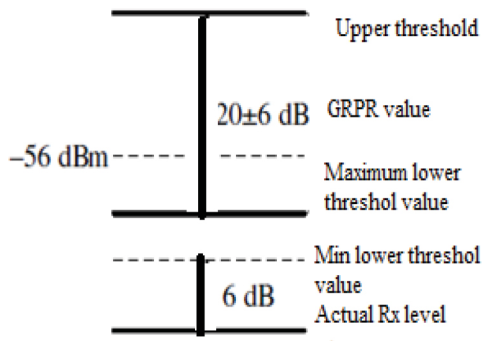


Figure 6. Relation between RSSI (dBm) and Distance (inches)

This law is mathematically verified and will be experimentally verified. On the basis of this these results the position estimation is calculated. Which will be used to reduce device discovery time in Bluetooth? RX power level are typically considered in wireless networks for measuring the transmit (TX) power control and distance estimations. In Bluetooth the RX power level is somehow indirectly connected to RSSI. The RX power level can be calculated using Read_TRANSMIT_POWER_LEVEL. The relation between RSSI and RX power level can be clarified from the definition of the Golden Receiver Power Range (GRPR). The following definition explains of GRPR.[17]



The value of RSSI can be converted to RX power only if the upper and lower threshold values are known,

IV. RADIO PROPAGATION MODEL

This model is used to estimate distance from the known value of RSSI and Tx Power level [16],[17].
Consider the following Friis equation.

$$Prx = \frac{(Ptx.Gt.Gr.d^2)}{(4\pi d)^2} \quad (5)$$

Taking log both sides of equation 5 and multiply it by 10 both sides. Then

$$10.\log 10\, Prx = 10.\log 10\, Ptx \left(\frac{(Ptx.Gt.Gr.\lambda^2)}{(4\pi d)^2} \right) \quad (6)$$

Therefore

$$10.\log 10\, Prx = 10.\log 10\, Ptx + 10.\log 10 Gt + 10.log 10\, Gr - 10.\log 10\ (\lambda/ 4\pi d)^2$$

$$10.\log 10\, Prx = 10.\log 10\, Ptx + 10.\log 10\, G + 20.\log 10(\lambda) - 20.\log 10\,(4\pi) - 20.\log 10\,(d) \quad (7)$$

Prx is known as the power received, by the receiver, Ptx referred above is the transmitted power which is taken in dB. Grx here represents the antennas gain power and Gtx represents the transmitted power of antenna. The unit for both is dBi. The velocity of light is represented by c, and the central frequency is referred as f. the values for c and f are as under c= 3.0 $*10^8$ m/s. and f =2.44 GHz. The variable n is used as the attenuation factor which is taken as 2 for (free space). Received in Bluetooth networks can be measured indirectly from RSSI. Figure 7 [16], shows the relationship of RSSI and received power level of Bluetooth networks.

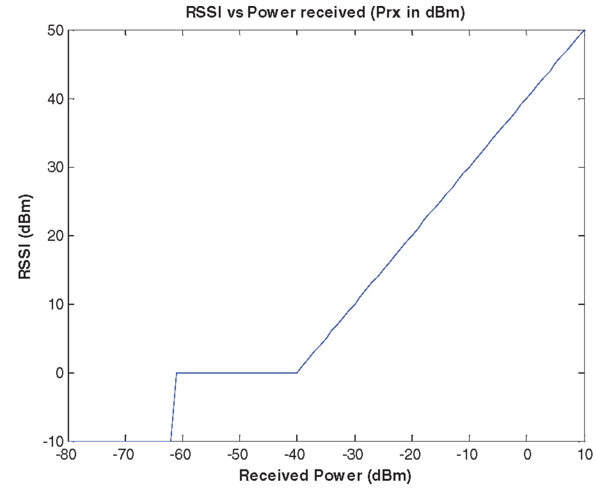


Figure 7. Relation between RSSI and Prx

Figure 7 [16], shows the relationship between RSSI and Prx , if the value of RSSI is zero then it means that power received Prx is within the GRPR range. But if the value of RSSI is greater than zero, then the received power Prx is greater than the upper threshold values (-40 dBm) conversely if the value of RSSI is less than zero or negative then power received will be less than the lower threshold value (-60 dBm)[16].

The estimated distance d, [17] can be obtained from the equation 6 and 7, will be

$$distance(d) = 10^{\wedge\,(Ptx - Prx + Gtx + Grx + 20\log(\lambda) - 20\log(4\pi))/20)} \quad (8)$$

The above mentioned radio propagation model derived from the Friis transmission equation is used to estimate the distance from the Received power which is indirectly obtained by converted RSSI values to Prx.

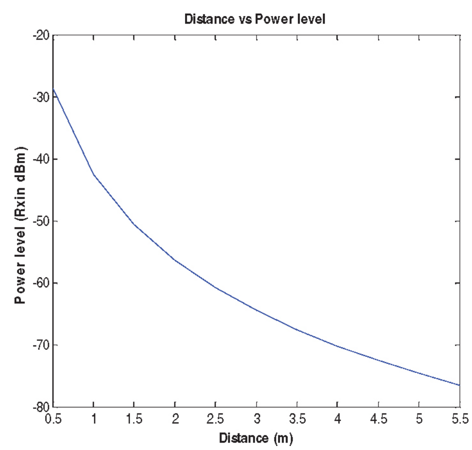


Figure 8. Received power Prx (dBm) vs distance (d)

Figure 8 [16], shows the received power vs distance. The theoretical values of Prx are taken from the radio propagation model. The values for equation (8) are taken as Ptx = 2.5dBm, n = 2, and G = -2.5dBi and λ is taken as 0.12 m.. The above graph shows that the received power when decrease the distance also increases. The results shows that the transmit power depends on the distance between transmitter and receiver.

V. Conclusion and Future work

In this paper Localization techniques for Bluetooth networks has been presented. RSSI and RX power level is considered for distance estimation using the radio propagation model. Distance is calculated from the propagation model and plotted with the RX power level. The relationship between RSSI and RX power level is calculated from the proposed model using Matlab. After analysis of the relation between the RSSI over Distance, it has been concluded the RX power level is the best option for Distance estimation. Our future work includes minimization of discovery time for Bluetooth networks based on the basis of RSSI and distance relationship. The results obtained from mathematical models shows that RSSI and RX power level are proportional to the distance. Further experiments needs to be done to get more distance estimations. So if the device position is already estimated. Then discovery process in Bluetooth will be reduced based on the values obtained from RSSI and device position in XY coordinates. Our future work also includes the implementation of roaming protocol for Bluetooth networks. To implement the roaming protocol we need to reduce the discovery and connection establishment time. If we reduce the time taken in whole Bluetooth device connection then soft handover can be implement using localization technique. RSSI is the main factor for starting the handover when a Bluetooth enabled device starts roaming from one piconet to another. On the basis of the RSSI and distance ratio handover will be initiated.

References

[1] Leeper, D., G. "A long-term view of short-range wireless," IEEE Computer Magazine, vol.34, no.6 pp.39-44, 2001

[2] Specification of the Bluetooth System (version1.1), Bluetooth Special Interest Group, [Available online, last accessed April 16, 2010] http://www.bluetooth.com

[3] Wikipedia Computer Dictionary, [Available online, last accessed April 16, 2010] http://www.bluetooth.com

[4] Sreenicas, H., and Ali, H. H., "An evolutionary Bluetooth scaternet formation protocol". Proceedings of the 37th Hawaii International Conference on System Science, vol 9,2004

[5] Roxin, A., Gaber, J., Wack, M., Nait-S.M. A., "Survey of wireless geolocation techniques" IEEE Workshop on Service Discovery and Composition in Ubiquitous and Pervasive Environments (SUPE) 2007.

[6] Aventhi., K., "Comparative study of RSS-based collaborative localization methods in wireles sensor networks". M.Sc Thesis Toulouse School of Graduate Studies Dec 2006

[7] Mao, G., Baris., Fidan., Anderson, D.O., "Wireless sensor network localization techniques" The International Journal of Computer and Telecommunications Networking vol 51,no 10 . pp. 2529-2553,2007

[8] Guolin, S., Jie, C., Wei, G., and Liu, K. J. R., "Signal processing techniques in network-aided positioning: a survey of state-of-the-art positioning designs," IEEE Signal Processing Magazine, vol. 22, no. 4, pp. 12–23, 2005

[9] Sayed, A. H., Tarighat, A., and Khajehnouri, N., "Network-based wireless location: challenges faced in developing techniques for accurate wireless location information," IEEE Signal Processing Magazine, vol. 22, no. 4, pp. 24–40, 2005

[10] Gustafsson, F,. and Gunnarsson, F. "Mobile positioning using wireless networks: possibilities and fundamental limitations based on available wireless network measurements," IEEE Signal Processing Magazine, vol. 22, no. 4, pp. 41–53, 2005.

[11] Koks, D. "Numerical calculations for passive geolocation scenarios", Tech. Rep. DSTO-RR-0000, 2005.

[12] Romer, A. "The lighthouse location system for smart dust," in Proceedings of MobiSys ACM/USENIX Conference on Mobile Systems, Applications, and Services, pp. 15–30, 2003.

[13] Bahl, P,. and Padmanabhan, V. "RADAR: an inbuilding RF-based user location and tracking system," IEEE INFOCOM, vol. 2, 2000, pp. 775–784.

[14] Bardwell, J, Wiledpackets 802.11 , [Available online, last accessed April 16, 2010] http://www.wildpackets.com/elements/whitepapers/Converting_Signal_Strength.pdf

[15] Pandey, S., Agrawa, P., " A Survey on localization techniques for wireless network"Journal of the chinese institue of Engineers, vol.29, No. 7,pp.1125-1148 (2006)

[16] Zhou, S., Pollard. , J.k., " Position measurement using Bluetooth" IEEE Transactions on Consumer Electronics, vol. 52, no. 2, p. 555, May 2006

[17] Kotanen, A., Hännikäinen, M., Leppäkoski, H., Hämäläinen, T. D., "Experiments on local positioning with Bluetooth," International Conference on Information Technology Computers and Communications" , pp. 297, 2003.