Bluetooth Indoor Location Determination System Using Heuristic Approach

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DECLARATION

We, hereby, declare that the work presented in this thesis is the outcome of the investigation performed by me under the supervision of Shadid Haque, Lecturer, Department of Computer Science and Engineering, BRAC University , Dhaka. I also declare that no part of this thesis and thereof has been or is being submitted elsewhere for the award of any degree or Diploma.

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Abstract

This paper presents a few methods to determine locations of arbitrary Bluetooth devices. These methods are essentially some improvement on existing methods. We use both theory and heuristic approach of real data to show the possibilities of these methods. We used Bluetooth devices for our lab experiments. Throughout this paper we focus on Bluetooth technology and leave it to the future work to do the same for other wireless devices.

We also suggest a distance measurement scale based on statistical analysis of the relation between Link Quality and Actual Distance as opposed to the relation between Transmit power level (TPL) and Actual Distance [1]. To determine location we use the triangulation method using at least three base stations. We show that it is possible to get a better approximation using more than three base stations by positioning them in a certain way.

We have collected large amount of data through our experiments but these experiments has limitation since there is not enough long spaces for talking data in long distances.

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1. Introduction

Recently, position based services have become very important. Application of this service can be very useful in Super Markets, Shopping Malls to determine positions of customers (e.g. tracking a lost baby in a Mall). In order to make these services feasible and useful, the accuracy of the determined position is the most important factor. To determine a position the measurement of distance is the prerequisite for triangulation method. But unfortunately Bluetooth devices provides very erroneous data that could lead to distance measurement.

Bluetooth provides few data that can be considered useful in Distance Measurement. They are Received Signal Strength Indicator (RSSI) and Link Quality(LQ) and Transmit Power Level(TPL). We choose to use LQ , RSSI , TPL for good reasons, which are explained in this paper. We gathered 50 readings of LQ , TPL, RSSI at each meter distance (from one meter to 10 meter) for client side and 1000 readings for sever side. From these data we suggest a new way to determine position of an arbitrary Bluetooth device.

Lastly, we show an improvement of the determined position's accuracy by positioning n>=3 base stations in a certain manner. Our research has just passed the initial stage and the result is this paper. Undoubtedly, much more future work will follow this paper to provide more evidence to prove our methods.

2. Bluetooth

Bluetooth is a specification that attempts to provide a standard method of wireless communication between personal devices. Devices with ranging complexity can utilize Bluetooth technology: from cellular phones to laptop computers. Today Bluetooth is integrated in almost every cell phone and laptop computers. Bluetooth has a complete software framework and it's own protocol stack (Figure 1).

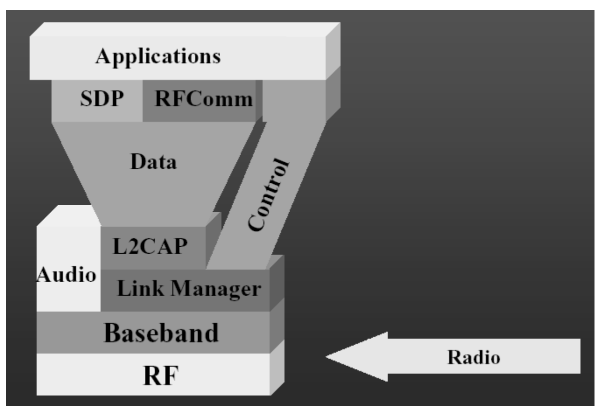

Figure 1: Bluetooth Protocol Stack

Bluetooth is surely a very feasible device in positioning system for it's small size, low cost and low power consumption.

2.1 Bluetooth Device Classes

There are three classes of Bluetooth devices.

1. Class 1: 100 mW, ~100 meter range.
2. Class 2: 2.5 mW, ~10 meter range.
3. Class 3: 1 mW, ~1 meter range.

Clearly, the classification is based on power consumption and range. Specification says class1 device better than others, which led us to use USB Class 1 devices to conduct our lab experiments.

2.2 Link Quality

The Bluetooth Specification defines a Link Quality parameter that can be used as a metric to determine the quality of the link with a specific device[6]. The specification does not define how the parameter is derived from measurable qualities of link. The definition of link quality is left up to the individual hardware manufacturers, and will probably be different for each manufacturer and possibly each model of device. It is likely that however Link Quality is defined it will degrade with distance between devices, and it may be possible to empirically determine a relationship between Link Quality reported by

a device and the distance to the remote device

2.3 RSSI

Most Bluetooth Devices implement a Received Signal Strength Indicator (RSSI) that allows the receiver to measure the received signal strength on a connection by connection basis[6]. It is well defined by the specification, accessible to user application through the use of standard HCI commands, and it is implemented on most devices, even when not required by the Bluetooth Specification. The RSSI values reported over the HCI are in relation to the limits of the Golden Receiver Range. The Bluetooth Specification defines a *Golden Receive Power Range* which is a 20 dB wide window in which the receiver would like to operate. A received signal that is above (stronger than) the Golden Range will be reported as a positive RSSI value and a received signal that is below (weaker than) the Golden Range will be reported as a negative value. Any signal that falls into the Golden Range will have a reported RSSI of zero. The width of the Golden Range is allowed to vary by up to 6 dB and the location of the bottom of the range could vary by as much as 40 dB as shown Figure2.

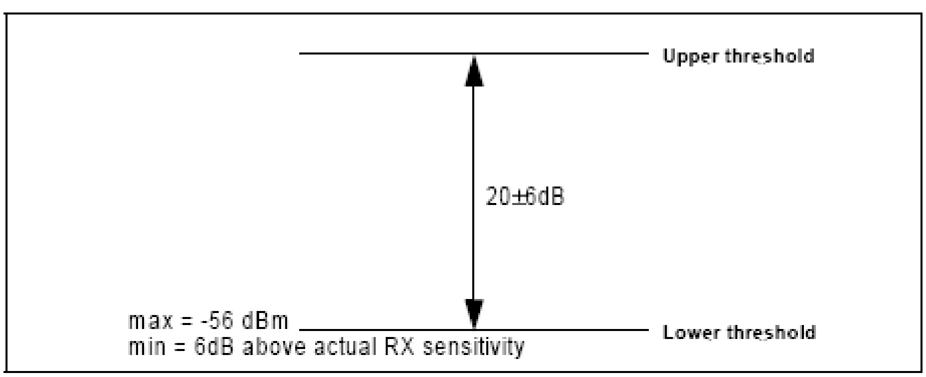

Figure2: Golden Received Power Range

2.4 Transmit Power level

Transmit Power level(TPL) is adjusted according to RSSI values. When RSSI value goes down, link manager of HCI increases its TPL value to adjust its RSSI value into zero and vise versa.

3. Distance Measurement

Measuring distance is the first and the most important step in Triangulation Method . In fact, this is the trickiest part in Bluetooth positioning system. Bluetooth stack provides a link quality value ranging from 0-255. We need to translate these link quality values to distance units (e.g. meters). This process has great challenges:

1. At a fixed distance the link quality varies dramatically.
2. Translation of link quality values to distance units is a mere approximation.

To overcome these challenges we need to find ways to improve the approximation. This narrows down our goal to finding an optimal translation algorithm that will improve the approximation.

3.1 Data Analysis by our Method

Theory says the value of LQ, TPL will give same in any particular distance. But the ugly reality is totally different. In any particular distance, the LQ,TPL values vary dramatically. One of the ugly realities has shown in the following table for 6 meter distance where LQ,TPL values vary severely.

LQ	RSSI	TPL
255	0	3
236	0	7
236	0	7
217	0	9
217	0	9
217	0	9
223	0	9
223	0	9
223	0	11
223	0	11
223	0	11
214	0	11
214	0	11
214	0	11
214	0	11

Table1: ugly reality of 6 meter distance

So we find a very successful method to eliminate bad data by hypothesis which gives us a good set of data more similar to our theory.

3.1.1 Collection of data

We set up our experiment into our ECE lab for collecting raw data . We used class1 Bluetooth USB Dongle both as server and client and took readings upto 10 meter distance. Each reading was triplet(LQ,RSSI,TPL) and took 50 readings in each meter distance. In figure3 has shown our experimental setup.

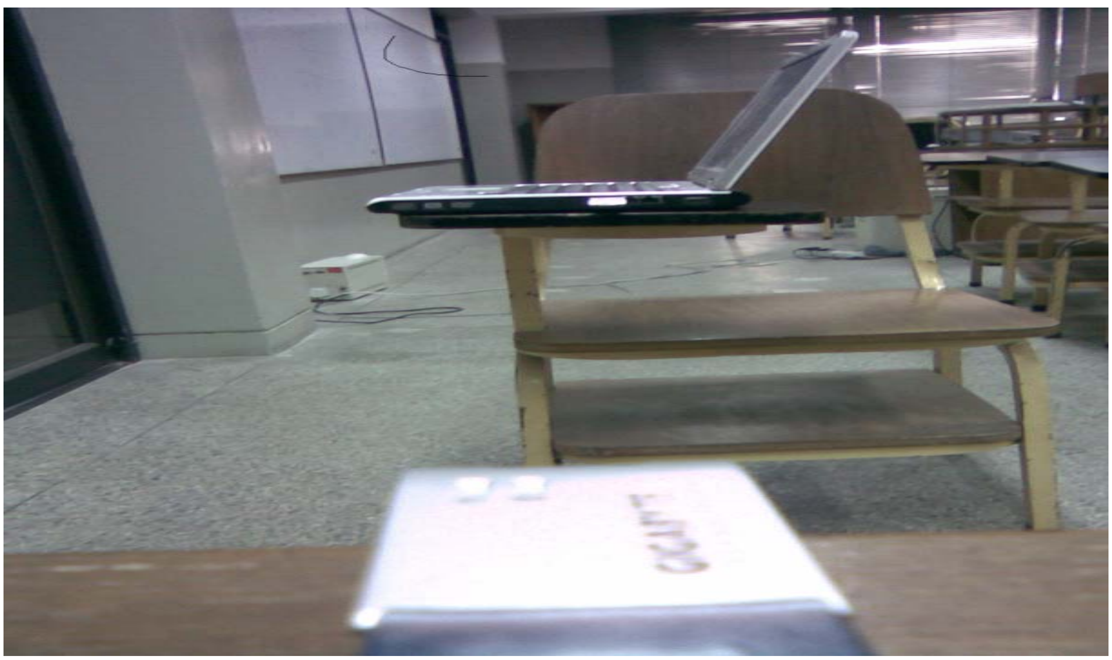

Figure3: Experiment set up

3.1.2 Bad Data Eliminate

We can surely eliminate the triplet those are negative or positive RSSI because As I mentioned RSSI within *Golden Range* returns us zero value which is theoretically accepted in any meter distance. For our next iteration, we can see that if we set our STDEV at 5.0 then it give us a very good set of data for our remaining distance calculation. So, we calculate STDEV and AVERAGE of LQ and TPL and identify the LQ outside the range AVERAGE(LQs) ± STDEV(LQs) and discard the corresponding triplets. Following is a set of 50 readings at distance 6 meter and is shown step by step elimination according our elimination method.

LQ	RSSI	TPL	LQ	RSSI	TPL
255	-3	3	243	0	11
223	0	11	243	0	11
223	0	11	246	0	11
228	0	11	246	0	11
228	0	11	246	0	11
228	0	11	246	0	11
228	0	11	248	0	11
231	0	11	248	0	11
231	0	11	248	0	11
231	0	11	248	0	11
231	0	11	249	0	11
230	0	11	249	0	11
230	0	11	249	0	11
230	0	11	249	0	11
236	0	11	249	0	11
236	0	11	250	0	11
236	0	11	250	0	11
236	0	11	250	0	11
236	0	11	250	0	11
240	0	11	251	0	11
240	0	11	251	0	11
240	0	11	251	0	11
240	0	11	251	0	11
243	0	11	249	0	11
249	0	11	249	0	11

Table2: Data at 6 meter distance

LQ	RSSI	TPL
223	0	11
223	0	11
228	0	11
228	0	11
228	0	11
228	0	11
231	0	11
231	0	11
231	0	11
231	0	11
230	0	11
230	0	11
230	0	11
236	0	11
236	0	11
236	0	11
236	0	11
236	0	11
240	0	11
240	0	11
240	0	11
240	0	11
243	0	11
243	0	11
243	0	11

LQ	RSSI	TPL
246	0	11
246	0	11
246	0	11
246	0	11
248	0	11
248	0	11
248	0	11
248	0	11
249	0	11
249	0	11
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250	0	11
250	0	11
250	0	11
251	0	11
251	0	11
251	0	11
251	0	11
249	0	11
249	0	11
249	0	11

Table3: Eliminated cells by first iteration

In the table3 has shown eliminated cells in the first iteration according to our second elimination method.

LQ	RSSI	TPL
236	0	11
236	0	11
236	0	11
236	0	11
236	0	11
240	0	11
240	0	11
240	0	11
240	0	11
243	0	11

LQ	RSSI	TPL
243	0	11
243	0	11
246	0	11
246	0	11
246	0	11
246	0	11
248	0	11
248	0	11
248	0	11
248	0	11
249	0	11
249	0	11
249	0	11
249	0	11
249	0	11
249	0	11
249	0	11
249	0	11

Table4: Eliminated cells by second iteration

In the table4 has shown eliminated cells in the second iteration according to our second elimination method.

Following has shown step by step the change of STDEV.

AVERAGE	241.36	-0.06	10.84
STDEV	8.977887	0.424264	1.131371

Table5: Before Elimination

AVERAGE	241.0816	0	11
STDEV	8.850228	0	0

Table6: After Elimination according to RSSI

AVERAGE	244.1786	0	11
STDEV	4.966954	0	0

Table7: After Elimination according to STDEV(LQ)

3.1.3 Compute

Now we got a good set of data after eliminating bad data. We apply our own formula for computing values of each meter distance. Following is our own formula and computed values.

((Avg_of_LQ * Avg_of_TPL/100) + Adjusted_TPL)

LQ	TPL	Adjusted TPL	Computed Value
255.00	3.00	69.54	77.19
252.02	5.00	115.90	128.50
254.56	9.92	229.95	255.20
231.17	10.60	245.71	270.21
239.71	10.94	253.48	279.70
244.18	11.00	254.98	281.84

Table8: Computed value

Here we took both average percent of LQ and adjusted TPL for calculating our values. If we look at the TPL values which are increasing from top to bottom for adjusting the LQ value at 255 which is our goal for each meter distance. But all the way LQ value 255

Is not desired , so we took TPL percentage of LQ value. TPL and LQ values were not in the same scale , for this reason we just adjusted our TPL value into LQ scale.

3.1.4 Match

For server data, we took 50 thousand readings in each meter distance and computed data set by the same method and we assign its corresponding distance into our data base. Now we match our client data very close to its server data and give output the corresponding distance. Following has shown the match between 1 to 6 meter distance.

Sever Data	Distance	Client Data
77.19	1	77.19
128.001	2	128.5
254.963	3	255.2
272.065	4	270.21
280.563	5	279.7
283.5321	6	281.84

Table9 : Match between server and client data set

4. Base Stations – How many and Where?

We can improve the distance approximation by positioning Base Stations wisely. The signal power decreases logarithmically with increasing distance [5]. So, the received signal power increases exponentially with decreasing distance. Some exceptions can occur according to what we found from our experiments. So, the accuracy of distance measurement increases with decreasing distance. Based on these theorem and experiments, we tried to strengthen the received signal quality using more than 3 base stations. The extra stations can be other cell phones in the area of coverage of the 3 main base stations. This situation is further explained in Figure 4.

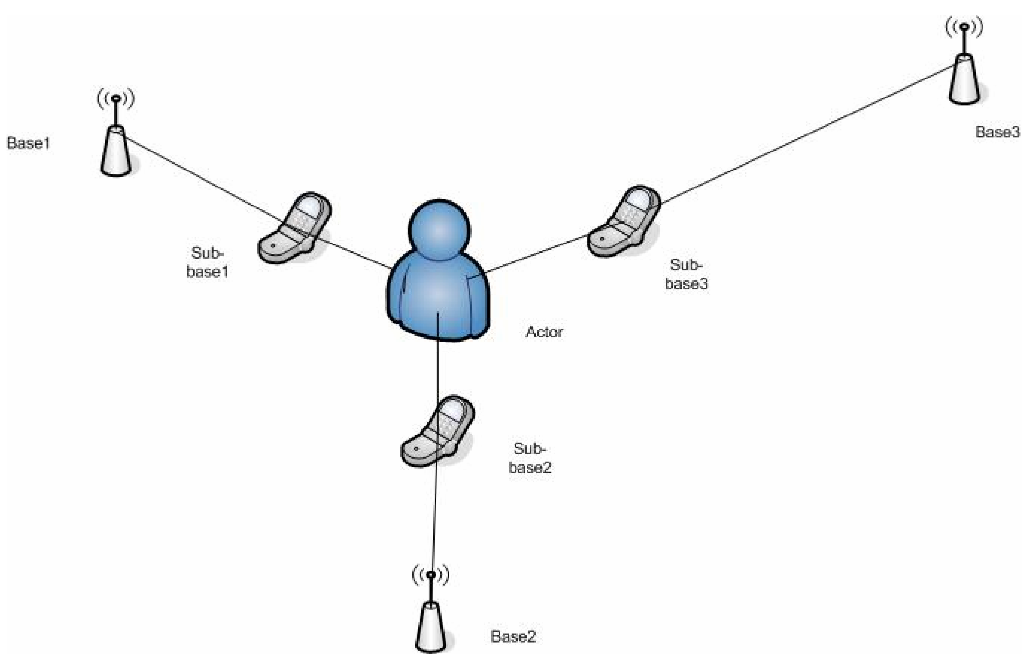

Figure 4

First we will find out the distance of the Sub-base1 from the Base1. Then we will find out the distance of our target actor from Sub-base1 instead of the Base1 because signal strength increases exponentially with decreasing distance. Now we will add these two distances to get the actual distance from the Base1 to target Actor. In this way, we will find out the distance from the other base stations. Based on these experiments, we can measure distance of our desired actor with improved accuracy within the area of coverage of 3 Base Stations and 3 Sub-base stations. Furthermore this idea can be extended to 3 Base Stations and n (>=3) Sub-base stations.

5. Assumptions and Limitations

We have not considered walls, temperature and other factors, which play an important role in Link Quality Computation. Future research should focus on these issues. Our experiments are done with two identical Class 1 Bluetooth devices. So this restricted our findings between these devices only. Experiments with other classes of Bluetooth devices should also be done to provide server data for those devices.

6. Conclusion

Working with wireless devices' Link Quality data is proven to be ugly. This implies a whole set of challenges to figure out an Indoor Positioning System. In this paper we have at least shown a method to determine distance from Link Quality with good accuracy and a separate set of methods to increase the accuracy even more. These methods may not be concretely proven yet but our experiments shows promising results as an encouragement for further research on this topic. If established, this method can open a whole new era of Indoor Positioning System.

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