VHDL Implementation of Robust Wi-Fi Positioning System

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ABSTRACT
Design of a cost effective and accurate positioning of a wireless device is one of the challenging issues in Wireless Local Area Networks (WLANs). In this paper we present a novel positioning system by utilizing WLAN received signal strength measurements. The technique includes two parts; First, distance estimation using received signal strength indication (RSSI) using polynomial fitting method. Second, simplified and accurate geometric location algorithm (GLA) is proposed. The proposed technique is less complex and easy to implement. The technique not requires any extra hardware and offline training.

This location algorithm is designed and tested in MATLAB tool and described using Very high speed integrated circuit Hardware Description Language (VHDL), synthesized in XILINX ISE 10.1 and simulated in ISE simulator. Novelty of the HDL description is that, IEEE754 floating point representation is used, which increases the accuracy.

Keywords
RSSI, WLAN, GLA, Positioning, VHDL, IEEE-754

1. INTRODUCTION
Positioning of objects and humans in both indoor and outdoor environment has become a more challenging research topic now a day, due to the improvements in the wireless communication technology. Global positioning system (GPS) is the most suitable for outdoor environment [1], as it is efficient, low cost and provides scalable positioning service. However using GPS scheme the signals received from the satellites are not efficient to calculate the indoor positioning of the objects.

Various accepted distance estimation methods in use are time of arrival (TOA) [4], time difference of arrival (TDOA) [5], angle of arrival (AOA) [6], and received signal strength indicator (RSSI) [14]. The synchronization requirement between transmitter and receiving nodes in TOA and TDOA, direction of radio waves calculation in AOA requires extra hardware. However, RSSI based mathematical models are less complex.

In this paper, first, RSSI based polynomial fitting algorithm [3] is used to calculate the distance between the base station (BS) and the mobile station (MS) and, second, geometric location algorithm [2] is used to locate the object. Calculation of this algorithm is done at the MS (mobile-based schemes). MS is equipped with battery. Conventional algorithm uses lot of computations hence energy. But, this geometric location algorithm reduces the computations carried out at the MS to reduce the power consumption. And also it is showed that this algorithm is accurate [2]. The main objective of our approach is to improve positioning accuracy and simplified calculations at the MS in the positioning process.

In this paper, section II describes related work. Section III describes the methodology of proposed design which includes polynomial fitting algorithm and geometric location technique. In section IV how proposed design is designed in IEEE-754 floating point representation is given. Finally results and conclusions are given in section V and VI respectively.

2. RELATED WORK
Various positioning estimation methods have been proposed to find the location of the MS using various parameters such as time of arrival (TOA) [4], time difference of arrival (TDOA) [5], angle of arrival (AOA) [6] and received signal strength (RSS) [14].

RSSI based distance estimation methods are becoming more popular because of simple and low cost. Geometric location algorithms are simple and accurate. There are many propagation models to describe indoor positioning system [7], Okumura model is applicable in large urban area but it respond slowly to the sudden changes in the terrain [8]. Hata model [9] uses graphical path loss data obtained by Okumura. It works well in the current cellular system but not suits indoor environment. Extension to the Hata model is COST231 model [7] ; it is suitable for urban, suburban and rural area. But diffractions from rooftops and buildings are not considered by this model. Egli's propagation model is simple and it assumes terrain with hill of approximately 50 feet height. But this is limited to flat surfaces [10]. In this paper we used polynomial fitting method to estimate the distance between AP and MS.

Positioning calculation can be done either at MS or BS. But positioning in BS involves high cost and low accuracy [11]. Hence, we go for MS based positioning. In this paper we used geometric location algorithm to estimate the position of MS because minimum instructions are used, these instructions are simple and can be easily executed at MS. Main motivation for this paper is low cost, simple and high accuracy.

3. METHODOLOGY
3.1 Design flow
Flow chart of the proposed localization algorithm is shown in Fig.1

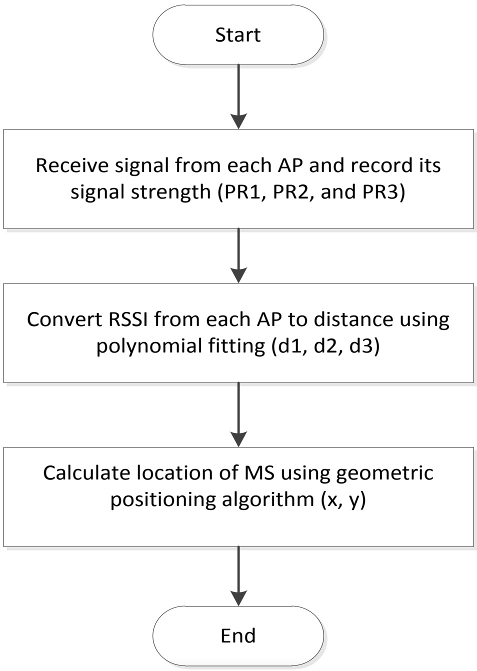

Figure 1. Design flow

3.2 Geometric location algorithm (gla)

GLA used here requires three APs. Consider that range circle of all three APs intersect at single point as shown in Fig.2

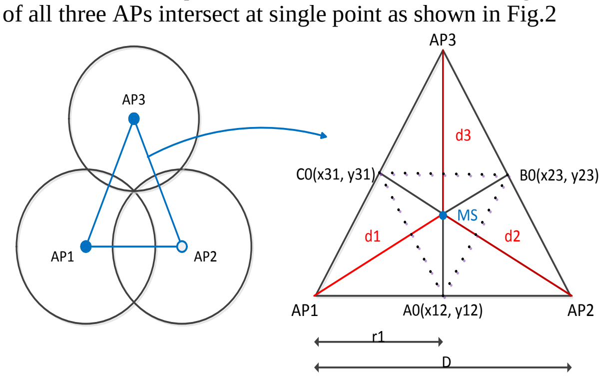

Figure 2. Intersection of three circles and associated triangles

Where,

D, The distance between any two APs

A0, B0 and C0 are the orthogonal projections of the MS on (AP_1, AP_2), (AP_2,AP_3) and (AP_2,AP_1) respectively

d_1, d_2 and d_3 are the distances between the MS and AP_1, AP_2 and AP_3 respectively calculated by the RSSI received from each APs which is given in next section

Some assumptions are made in the GLA [2]. First, All three APs are placed at each corner of the equilateral triangle. Hence, distances between any two APs are same. Second, coordinates of APs are initially known to MS. Third, Now MS can be placed anywhere inside the triangle.

Distance between AP_1AP_2, AP_2AP_3 and AP_3AP_1 are calculated as below

$$D_1 = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \quad (1)$$

$$D_2 = \sqrt{(X_2 - X_3)^2 + (Y_2 - Y_3)^2} \quad (2)$$

$$D_3 = \sqrt{(X_3 - X_1)^2 + (Y_3 - Y_1)^2} \quad (3)$$

Distance between AP_1 and orthogonal projection of MS on AP_1AP_2 is r1 and it is given in [12] as,

$$r_1 = \frac{D_1^2 + d_1^2 - d_2^2}{2D_1} \quad (4)$$

And one intermediate factor q_1 is defined as

$$q_1 = \frac{r_1}{D_1} = \frac{D_1^2 + d_1^2 - d_2^2}{2D_1^2} \quad (5)$$

Using this q1, coordinate of point A0 i.e., (x_{12},y_{12},) are given by [12] as

$$\left.\begin{aligned} x_{12} &= q_2X_2 + (1 - q_1)X_1 \\ y_{12} &= q_2Y_2 + (1 - q_1)Y_1 \end{aligned}\right\} \quad (6)$$

Where (X_1,Y_1) and (X_2, Y_2) are coordinates of AP_1 and AP_2 respectively. Similarly (x_{23},y_{23},) and (x_{31}, y_{31},) are calculated as shown in [12]

Now new virtual APs are placed at A0, B0 and C0. Distance between MS and these A0, B0 and C0 are calculated using Pythagoras formula as shown below

$$\left.\begin{aligned} d_1(MS, A_0) &= \sqrt{d_1^2 - r_1^2} \\ d_2(MS, B_0) &= \sqrt{d_2^2 - r_2^2} \\ d_3(MS, C_0) &= \sqrt{d_3^2 - r_3^2} \end{aligned}\right\} \quad (7)$$

3.3 Algorithm

Step 1. Calculate D_1, D_2 & D_3 using (1), (2) & (3)

Note: In first iteration D_1=D_2=D_3

Step 2. Calculate r_1, r_2 & r_3 using (4). Using (5) calculate q1, q2 & q3

Step 3. Using these q_1, q_2 & q_3 and (X_1, Y_1), (X_2, Y_2) & (X_3, Y_3) calculate (x_{12}, y_{12},), (x_{23},, y_{23},) & (x_{31}, y_{31},) as given in (6)

Step 4. Update d_1, d_2 and d_3 using (7)

Step 5. Update (x_{12}, y_{12},), (x_{23}, y_{23},) & (x_{31}, y_{31},) as (X_1, Y_1), (X_2, Y_2) & (X_3, Y_3)

Step 6. Repeat step 1 using the updated values obtained in step 4 and step 5 till x_{12}~x_{23}~x_{31} and y_{12}~ y_{23}~y_{31}

Step 7. Calculate (X, Y) using below formulas

$$X = \frac{x_{12} + x_{23} + x_{31}}{3} \quad and\ Y = \frac{y_{12} + y_{23} + y_{31}}{3}$$

3.4 Polynomial fitting algorithm

RSSI values received from each AP are converted into distance using this algorithm. The signal propagation model which is most used is log-normal shadowing model [14]:

$$P(d)_{dBm} = P(d_0)_{dBm} - 10n\log\left(\frac{d}{d_0}\right) + X_0$$

Where, P (d_0) is the path loss at distance of d_0 meters. d_0 value is assumed to be 1m, and *n* is the path loss exponent. X_0 is the RSSI measurement noise. This model cannot characterize RSSI data and distance relationship [13]

Because of the different indoor environment, to fit various situations various indoor wireless signal transmission models are adopted, a set of some indoor data is measured in the paper and corresponding wireless transmission model is found which improve the precision of the following localization calculation.

Polynomial fitting can be defined as [3]

$$d=f(P)=\alpha_0+\alpha_1 P+\alpha_2 P^2+..+P^m+\omega \qquad (8)$$

Where, P is the received signal strength, d is the distance between the transmitter and receiver, $\alpha = [\alpha_0, \alpha_1, \dots, \alpha_m]^T$ is the fitting coefficient. m is the polynomial fitting order which is taken as 3 in our paper. Its calculation is given in [3].

The ith measurement is for i=1... n:

$$d_i=f_i(P_i)=\alpha_0+\alpha_1 P_i+\alpha_2 P_i^2+..+\alpha_m P_i^2+\omega_i \qquad (9)$$

Least square estimation of $\hat{\alpha}$ with least errors is as follows

$$\hat{\alpha} = (P^T P)^{-1} P^T D \qquad (10)$$

Where,

$$D = [d_1, d_2, \dots, d_n]^T,$$

$$P = \begin{bmatrix} 1 & P_1 & \cdots & P_1^m \\ 1 & P_2 & \cdots & P_2^m \\ \vdots & \vdots & \vdots & \vdots \\ 1 & P_n & \cdots & P_n^m \end{bmatrix}$$

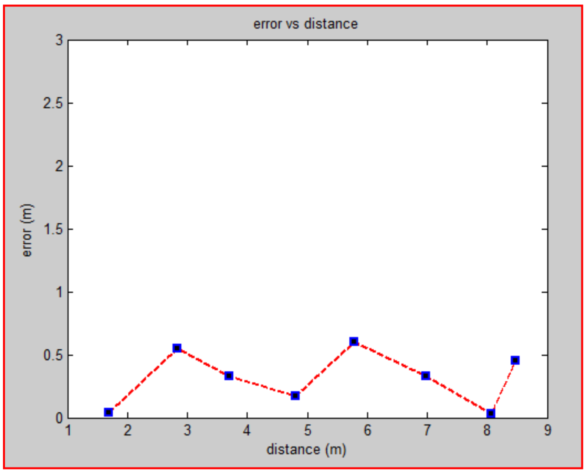

Figure 3. Measured distance error versus distance

Accuracy and error using this polynomial fitting algorithm is given in Fig.3 which is less than 0.5m

4. VHDL DESIGN

The proposed design is described in VHDL language using IEEE-754 floating point representation. IEEE-754 representation is used to represent the floating point number in binary format. There are three formats

1) Half precision (16 bit)
2) Single precision (32 bit)
3) Double precision (64 bit)

In our design we used single precision format because of its high accuracy compared to half precision and less hardware is required than double precision. Sign bit, number of exponent bits, mantissa bits, precision are given in [16].

5. RESULTS

Experiments are carried out to take RSSI measurements using d-link Wi-Fi adapter and NetStumbler software [15].

Table 1 shows the results of the GLA using empirical values of d_1, d_2 and d_3. The error obtained using empirical values of d_1, d_2 and d_3 is 0.062m.

Table I. Position estimation using actual d_1, d_2 and d_3

X_{actual} (meter)	Y_{actual} (meter)	$d1_{actual}$ (meter)	$d2_{actual}$ (meter)	$d3_{actual}$ (meter)	$X_{estimated}$ (meter)	$Y_{estimated}$ (meter)	Error (meter)
2	1	2.23	8.06	8.26	2.00	0.91	0.09
3	2	3.61	7.28	6.99	3.00	1.92	0.08
4	3	5.00	6.70	5.78	4.01	2.94	0.07
4	4	5.65	7.21	4.80	3.99	3.95	0.06
5	5	7.07	7.07	3.70	5.00	4.96	0.04
5	7	8.60	8.60	1.70	5.00	6.98	0.02
6	6	8.48	7.20	2.88	6.00	5.96	0.04
6	4	7.20	5.65	4.80	5.99	3.94	0.07
7	3	7.62	4.24	6.04	7.00	2.94	0.06
8	2	8.24	2.83	7.34	7.99	1.92	0.09
						Mean	0.062

Table II. Comparison of MS coordinates, (X, Y) obtained by experimental values with actual values

X_{actual} (meter)	Y_{actual} (meter)	Using MATLAB			Using VHDL		
		X_{est} (meter)	Y_{est} (meter)	Localization Error (LE1) (meter)	X_{est} (meter)	Y_{est} (meter)	Localization Error (LE2) (meter)
2	1	2.16246998	1.19683866	0.2552	2.16246986	1.19684374	0.2552
3	2	2.49641364	2.13423568	0.5212	2.48765873	2.13423776	0.5296
4	3	4.25721245	3.35509385	0.4385	4.25720453	3.35509967	0.4385
4	4	3.61956190	4.16909936	0.4163	3.61956095	4.16910266	0.4163
5	5	4.99999999	5.52574095	0.5257	5.00000238	5.52574682	0.5257
5	7	5.00000000	6.38348530	0.6165	5.00000572	6.38327374	0.6167
6	6	5.50543779	6.13979977	0.5139	5.50543403	6.13981294	0.5139
6	4	6.38043809	4.16909936	0.4163	6.38044357	4.16910289	0.4163
7	3	7.51400680	2.41908622	0.7757	7.51407194	2.41908931	0.7757
8	2	8.04988319	1.62541659	0.3779	8.04988479	1.62541341	0.3779
		Mean = 0.4857			Mean = 0.4866		

Table 2 shows the comparison of (X, Y) coordinates values i.e., actual coordinates, values obtained by

MATLAB implementation and values obtained by VHDL implementation. It also gives the localization error (LE), which is the distance between actual coordinates and estimated coordinates. LE 1 and LE2 are the localization errors with respect to actual coordinates and coordinates obtained by MATLAB and VHDL. These are given by (8) and (9) respectively

$$\mathrm{LE1} = \sqrt{(\mathrm{X_{act}} - \mathrm{X_{MAT}})^2 + (\mathrm{Y_{act}} - \mathrm{Y_{MAT}})^2} \qquad (8)$$

$$\mathrm{LE2} = \sqrt{(\mathrm{X_{act}} - \mathrm{X_{VHDL}})^2 + (\mathrm{Y_{act}} - \mathrm{Y_{VHDL}})^2} \qquad (9)$$

From the table we can observe that, LE1 is 0.4857m and LE2 is 0.4866m.

5.1 MatLab simulations

Simulations are carried out by taking the APs locations as follows: AP_1AP_2, AP_2AP_3

AP_1- $(X_1,Y_1) = (0, 0)$

AP_2- $(X_2,Y_2) = (10, 5)$

AP_3- $(X_3,Y_3) = (5, 8.6)$

The above simulation is carried out for 8 iterations and then we find that results converge to the actual values. Variation of the X-coordinates, x_{12}, x_{23} and x_{31}, Y-coordinates y_{12}, y_{23} and y_{31} and average of these values i.e., (X, Y) in every iteration are given in Fig.4, Fig.5 and Fig.6 respectively

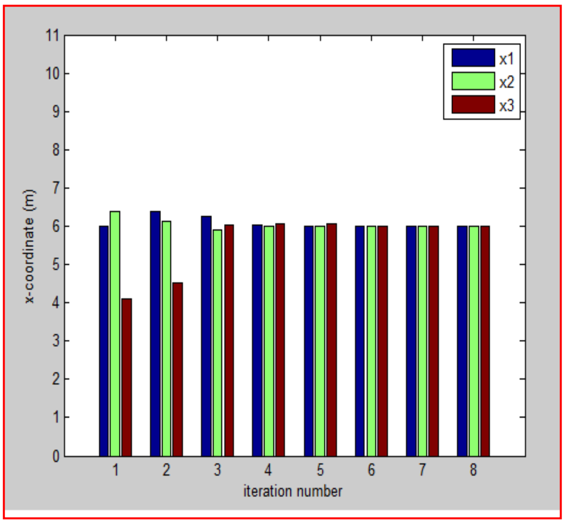

Figure 4. Variation of x-coordinates with iteration number

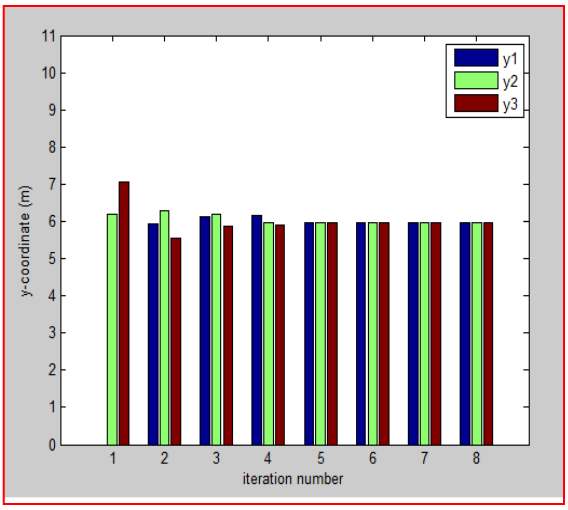

Figure 5. Variation of y-coordinates with iteration number

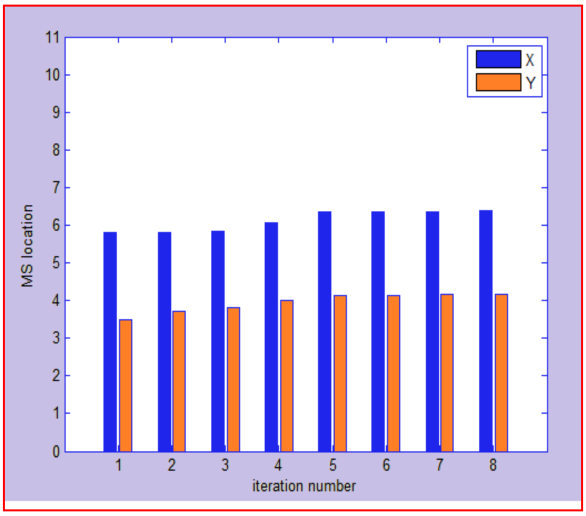

Figure 6. Variation of (X, Y) with iteration number

5.2 VHDL results

VHDL Implementation of GLA using IEEE754 32-bit single precision floating point representation is given in this section.

The proposed design is synthesized at RTL level using XILINX ISE 10.1 software targeted to the device 5vlx110tff1738 with speed grade of -2. Top module is shown in Fig.7 and RTL schematic of GLA is shown in Fig.8

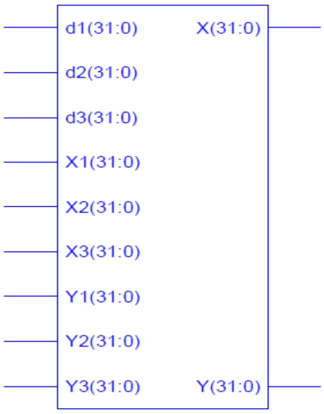

Figure 7. Top level RTL schematic

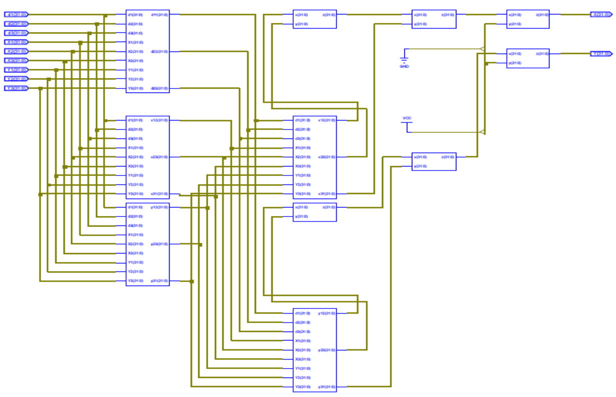

Figure 8. RTL schematic of GLA

Fig.9 shows the VHDL simulation of our positioning technique for MS coordinate values (6, 4), Expected values of (X, Y) are (6.38043809, 4.16909936), and obtained values of (X, Y) using VHDL simulation are (6.38044357, 4.16910289). Error obtained is (0.00000548, 0.00000353). Simulations are carried out using ISE simulator.

Device utilization summary of the synthesis process is given in table 3

Table III. Device utilization summary

Device Utilization Summary (estimated values)			
Logic Utilization	Used	Available	Utilization
Number of Slice LUTs	29421	69120	42%
Number of fully used LUT-FF pairs	0	29421	0%
Number of bonded IOBs	381	680	56%
Number of DSP48Es	54	64	84%

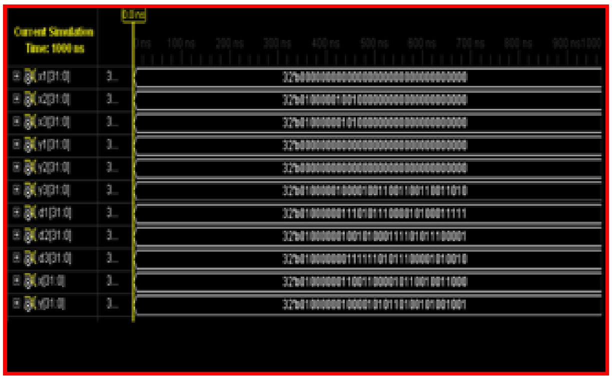

Figure 9. Simulation of GLA

6. CONCLUSION

Proposed location algorithm provides accurate WLAN positioning technique. Real time RSSI values are used to obtain the position of the MS from set of distance estimations to the access points. We have compared localization error through numerical simulations and real experiments. Accurate results are obtained. Comparisons of the MS coordinates obtained by MATLAB and VHDL with actual coordinates are presented.

The system is tested and validated in MATLAB and is described in VHDL language using XILINX ISE10.1 tool and is simulated using ISE simulator. IEEE-754 single precision floating point representation is used, which increases the accuracy of the positioning system. The technique could be extended to WLANs in other environments such as office, auditorium and industry.

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