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Spatial Analysis of Signal Strength in a Wireless Communication Medium for Indoor Geolocation System

J. Agajo, O. Joseph, S. E. Ezewele, and A. Theophilus

Abstract—**This paper tends to address the problem of having to track devices within an indoor location, Spatial analysis of signal with respect to particular location was carried out, it deploys the use of IEEE 802.11b WLAN Protocol. CDMA is adopted as its multiple access technique , a commonly used term FINGERPRINT used in indoor geolocation system technique seek to exploit the relationship between measurable physical stimulus and a specific location. Comparison between simulation result and mathematical model was carried out.**

Index Terms—**Indoor, geolocation, received signal, strength, wireless, finger print, Mathematical Model.**

I. Introduction

When we talk about an indoor geolocation system within a space, we are talking about a system that has the ability to locate the position of a mobile device, unit or station (MS) that is wirelessly connected to its network. The geolocation system technology has passed through a lot of improvements over the years. From the global positioning system (GPS) and the time of arrival technique (TOA), to the time difference of arrival (TDOA), the phase difference of arrival (POA) and received signal strength (RSS), researches have been on in areas of analysis and improvements. Among the techniques listed above, only the RSS technique is used mainly for indoor environment, as the others are used predominantly in outdoor environment, with some exceptions. A lot of researches are being undertaken in the indoor geolocation system because of its interesting applications and the numerous factors that affect the propagation of radio frequency (RF) signals in an indoor environment. The indoor radio propagation channel is characterized as site-specific, severe multipath fading and low probability of line-of-sight (LOS) signal propagation path between the transmitter and the receiver [2].

A common term used in indoor geolocation system is location fingerprinting. This refers to a technique that exploits the relationship between any measurable physical stimulus and a specific location [4].

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Application for indoor geolocation system consist of three main categories; commercial, public safety and military applications [1, 2]. In commercial applications in residential and nursing homes there is an increasing need for indoor geolocation system to track people with special needs, the elderly, and children who are away from visual supervision, to navigate the blind, to locate the in-demand portable equipments in the hospitals and to find specific items in warehouses [1]. In public safety and military application, indoor geolocation system are needed to track inmates in prison and navigating policeman, fire fighters and soldiers to complete their mission inside buildings. [1]

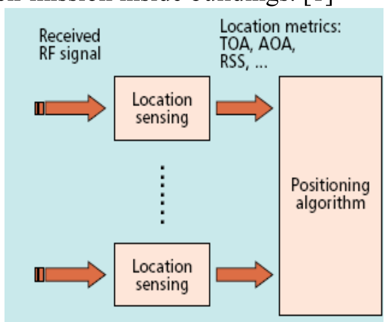

Fig. 1.0 A block diagram of a geolocation system.

A. Network Stumble

The Nets tumbler software reports information on the signal at different points, as the MS (which in the case of this research the laptop is used) is carried around the environment. For each or the APs, the software displays the medium access control (MAC) address, service set identifier (SSID), wired equivalent privacy (WEP) status, signal strength, signal to noise radio (SNR), noise, speed. Figures 2.0, 3.0 and table 1.0 shows the Nets tumbler software window at coordinate portable equipments in the hospitals and to find specific items in warehouses [1]. In public safety and military application, indoor geolocation system are needed to track inmates in prison and navigating policeman, fire fighters and soldiers to complete their mission inside buildings [1]

B. Network Stumble

The Nets tumbler software reports information on the signal at different points, as the MS (which in the case of this research the laptop is used) is carried around the environment. For each or the APs, the software displays the medium access control (MAC) address, service set identifier (SSID), wired equivalent privacy (WEP) status, signal strength, signal to noise radio (SNR), noise, speed. Figures 2.0, 3.0 and table 1.0 shows the Nets tumbler software window at coordinate (5,2), the blueprint of the departmental building (showing main lecture hall, corridors and grid pattern) and the database of the area.

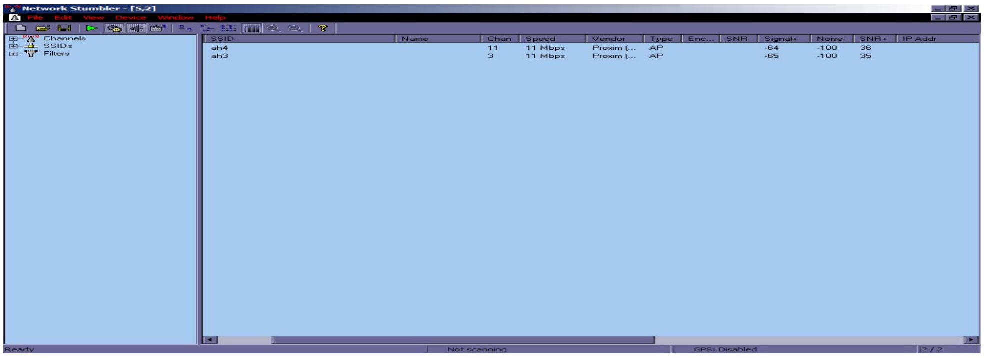

Fig. 2.0. The Nets tumbler software window.

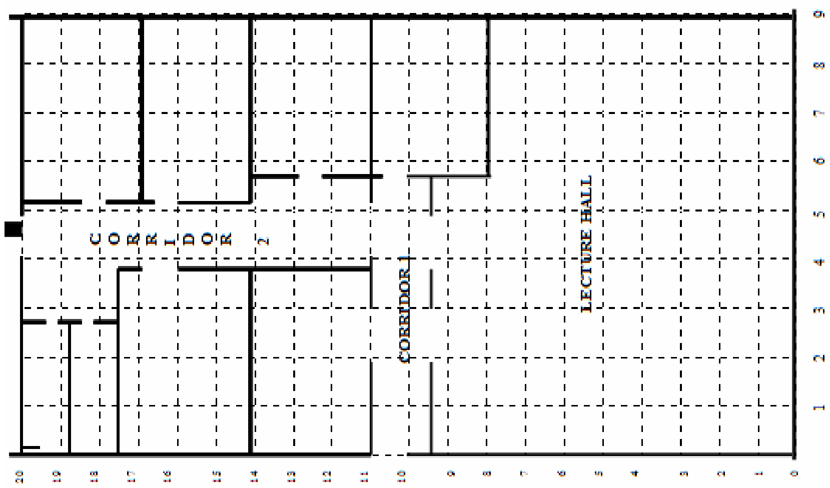

Fig. 2.1. Blueprint of the a building

Note that the RSS values or measurement are in dBm as could be seen in the database. This is more convenient than using just dB, which is only a ratio of power or voltage [11]. In calculating dB (which is a reference value) we use

$$10\log(\text{power in mW}/1\text{mW}) \quad (1)$$

or

$$10\log(\text{power in W}/0.0001\text{W}) \quad (2)$$

The letter after dB means that the 0-dB point reference is 1mW [11].

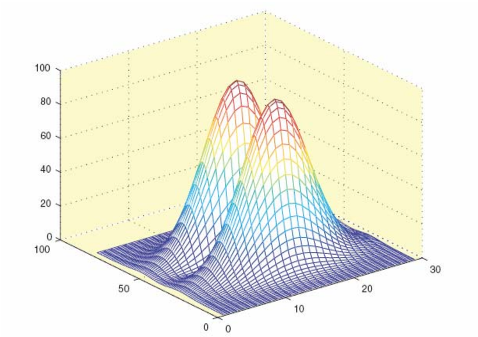

Fig. 3.0 .Showing signal flux spread

TABLE 1.0 FINGERPRINT DATABASE OF LOCATION

Access Points(APs)	AP1(ah4)	AP2(ah3)
Coordinates	dBm	dBm
(0,0)	-76	-71
(5,0)	-75	-71
(9,0)	-75	-71
(0,1)	-74	-71
(5,1)	-73	-71
(9,1)	-73	-71
(0,2)	-64	-65
(5,2)	-64	-65
(9,2)	-64	-64
(1,3)	-64	-63
(9,3)	-64	-63
(4,6)	-64	-62
(3,5)	-64	-61
(9,5)	-64	-61
(5,8)	-64	-60
(0,10)	-64	-59
(4,10)	-64	-59
(5,12)	-63	-59

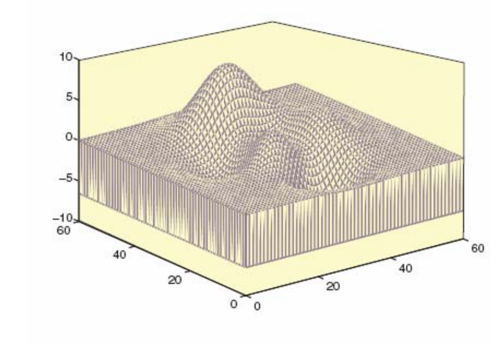

Fig. 4.0 Showing signal variation on a plane

The above database is what is stored in the server of the system, with which actual position location estimation is done. As can be seen in the table, the various coordinates are written against their various signal strength reading from both APs. Observe that NOT all the points in the grid were used in the database. This is because of the fact that the coordinates are close to each other and are bound to have similar signal strength, which is exactly what was realized in the course of this work and so some points on the grid were omitted to minimize this occurrence.

II. Mathematical Model

In establishing a model based on the data gotten from Received Signal Strength Indicator (RSSI), Software like NETWORK STUMBLER which tends to evolve data within a 3D setup is a position estimator that give a corresponding signal strength intensity with respect to distance, the vector diagram below shows direction of spread of signal, the cuboid is a representation of the space.

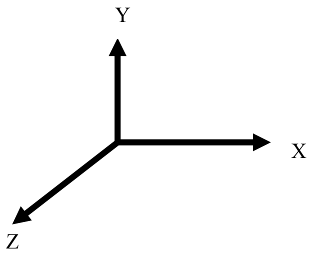

Fig. 4.0 Vector Diagram

The range of transmitted signal from the access point can be received within the following boundaries.

For space represented by rectangular coordinate the range below is taken

$$0 < X < 10$$
$$0 < Y < 15$$
$$0 < Z < 10$$

The space Vector can written as A_X, A_Y, A_Z or ($A_X a_x + Aya_y + Aza_z$) where ax, a_y, a_z are unit vectors along x, y, z direction respectively.

Beside calculating distance using Cartesian coordinate distance could also be calculated in the event of a cylindrical or spherical space setup, the cylindrical dimension will involve taken range between φ, ρ, ∞

The boundaries are taken between

$0 \le \rho \le \infty$, O ≤ φ

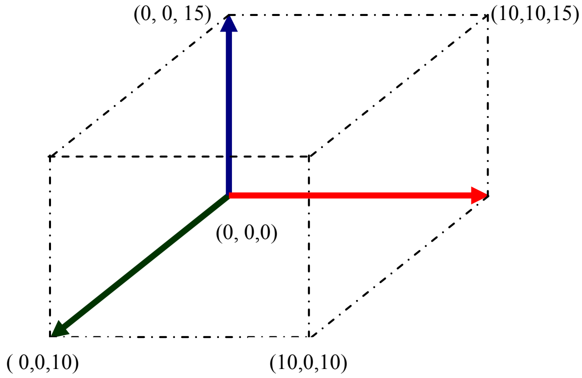

Fig. 5.0 .Vector representation in a cuboid

≤ 2π and ∞ ≤ Z ≤∞

Within a spherical enclosure written as Ar, $A\theta$ and $A\varphi$

If the indoor setup is a spherical setup the range taken between

$0 \le r \le \infty$, $0 \le \theta \le \pi$ and $0 \le \varphi \le 2\pi$

At any arbitrary point in within a space be it rectangular, cylindrical or spherical signal can be analyses.

To plot points and data collected from the coordinates on the graph, deviation of data from supposed data is plot on the graph as error range as shown in the graph below.

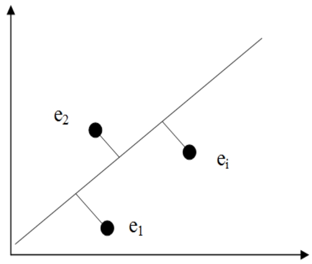

Fig. 6.0 Error range

e represent Error range from the actual supposed expected value.

e=error

Let S = signal strenght intensity from transmiting access point

D = distance away from access point one AP1

$$e_i = s - s_i$$

$$e^2{}_i = \sum_{i=1}^{n} (s - s_i)^2$$

square of error ranges gives[12]

$$\sum_{i=1}^{n} e^2 = (s_1 - s) + (s_2 - s) + (s_n - s) \quad (1)$$

let ∅= sum of square of errors

$$\phi = \sum_{i-1}^{n} (s - (ad + b))^2$$
$$= \sum y_i - ad - b^2)$$

error is minimise when we differentiate equation 1 with respect to a & b.

$$d\phi / da = 2\sum_{i-1}^{n}(s - ad - b)(-a) = 0$$

$$-\sum ds + a\sum_{i=1}^{n} x^2 + b\sum_{i=1}^{n} x_i = 0$$

$$d\theta / db = 2\sum_{i=1}^{n}(s - ad - b)(-1) = 0$$

$$\sum_{i=1}^{n} s = a\sum_{i=1}^{n} d + \sum_{i=1}^{n} b$$

$$\sum_{n=1}^{n} s = a\sum_{i=1}^{n} d + nb \qquad (2)$$

$$\sum_{i=1}^{n} ds = a\sum_{i=1}^{n} d^2 + b\sum_{i=1}^{n} d \qquad (3)$$

Combining equation 2 & 3

$$A = \frac{(\sum s)(\sum d^2) - (\sum d)(\sum ds)}{n\sum d^2 - (\sum d)^2}$$

$$b = \frac{n\sum ds - (\sum d)(\sum s)}{n\sum d^2 - (\sum d)^2}$$

$$y = a + bd \qquad (4)$$

TABLE 3.0 SHOWING SIGNAL STRENGTH AGAINST DISTANCE

n	d	s	d^2	ds	s^2
1	0.00	-71	0.0000	0.00	8041
2	1.00	-71	1.0000	-71.00	5041
3	2.00	-65	4.0000	-130.00	4225
4	3.16	-63	9.99856	-199.08	3969
5	5.00	-71	25.0000	355.00	5041
6	5.09	-71	25.9080	-361.39	5041
7	5.39	-65	29.0520	-348.40	4225
8	5.83	-61	33.9900	-355.63	3721
9	7.21	-62	51.9840	-447.02	3844
10	9.00	-71	81.0000	-639.00	5041
11	9.06	-71	82.0840	-643.26	5041
12	9.25	-64	85.1930	-590.72	4096
13	9.43	-60	88.9250	-565.80	3600
14	9.47	-63	89.6800	-596.61	3969
15	10.0	-59	100.0000	-590.00	3481
16	10.29	-61	105.8800	-627.69	3721
17	10.8	-59	116.6400	-637.20	3481
18	13.0	-59	169.000	-767.00	3481
	∑123.76	∑s= -1167.00	∑ d2=1099.39	∑ds=-9924.8	$\sum s^{2=}$ 76059

S = Signal strength, D = Distance form access Point, n=18 , $\sum d$=123.76 , $\sum s$=-1167.00 , $\sum d^2$=1099.39 , $\sum ds$=-9924.80 , $\sum s^2$=76059

$$a = \frac{N(-1167)(1099.39)-(123.76)(-9924.8)}{N(1099.39)-(123.76)^2}$$

$$a = \frac{18(-1167)(1099.39)-(123.76)(-9924.8)}{18(1099.39)-(123.76)^2}$$

$$= \frac{(-21006)(1099.39)+(1228293.2)}{19789.02-15316.38}$$

$$= \frac{-23093786+1228293.2}{4472.64}$$

$$a = \frac{-21865493}{4472.64}$$

$= -4888.72$

$$b = \frac{n\sum ds - (\sum d)(\sum s)}{n\sum d^2 - (\sum d)^2}$$

$$= \frac{18(-9924.8)-(123.76)(-1167)}{18(1099.39)-(123.76)^2}$$

$$= \frac{-178646.4+144427.92}{19789.02-15316.538}$$

$$d = \frac{-34218.48}{4472.482}$$

$= -7.651$

$$S = bd + a$$

$S = -7.651d - 4888.72$

Comparison between result obtained from mathematical model and that gotten from simulated result suffers some degree of degree of weak correlation. This was achieved by comparing the flow result using equation below[12].

$$R = 1 - 6\sum d^2 / N(N^2 - 1) \qquad (5)$$

Simulation using Position estimation to evaluate signal strenght

In the determination estimation of the MS, different algorithms are used. Location estimation algorithm or positioning algorithms are procedures that exploit dependency between location information and location fingerprint basis in order to determine a position or location from samples of RSS signals [4]. Several algorithms have been used for indoor geolocation system. Some of these are closest neighbour, neural network method, probability method and support vector machine method [4]. Note that the MS reports sample RSS vector to the central server (that contain the database) where the algorithm is used for position location determination [4].

However, one will make use of the closest neighbour technique that has to do with the calculation of the Euclidean distance. In calculating the Euclidean distance between sample RSS vector at any point and the average RSS vector on the database, we obtain the signal distance. The sample RSS vector used here refers to the location signal strength obtained during the online phase by an MS, while the average RSS vector is the fingerprint of the different coordinates that were obtained in the offline phase and saved in the database. The sample RSS vector and average RSS vector are here represented as $S=[s_1,s_2,s_3,\ldots s_n]$ and $A=[a_1,a_2,a_3,\ldots a_n]$ respectively. The elements s_1, s_2, a_1, a_2 etc represent the signal strength measurements at any particular location, for all N number of the APs. The Euclidean distance is calculated by the formula;

$$D_E = \sqrt{\sum_{i=1}^{n} (S_i - a_i)^2} \qquad (6)$$

A sample calculation of Euclidean distance is as shown below:

If a particular location, the MS register S = {-72, -71} as the sample RSS vector, then to calculate the Euclidean distance from, say the first coordinate on the ratio map, we would have

$$D_E = \sqrt{\sum_{i=1}^{n} (S_i - a_i)^2}$$
$$= \sqrt{([-72 - (-76)] + [-71 - (-71)]^2)}$$
$$= \sqrt{4^2 + 0^2}$$
$$= 4dBm$$

This calculation is repeated for all coordinate in order to determine the smallest and as such the closest. A fast way of carrying out this calculation is by use of such software application as Matlab. The above example is repeated for all coordinates using matlab, as shown in figure 3.0

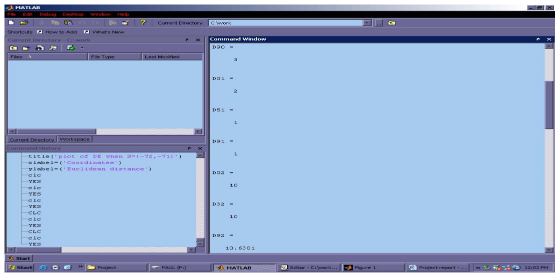

Fig. 7.0 Matlab command window showing the value of. Of Euclidean distance

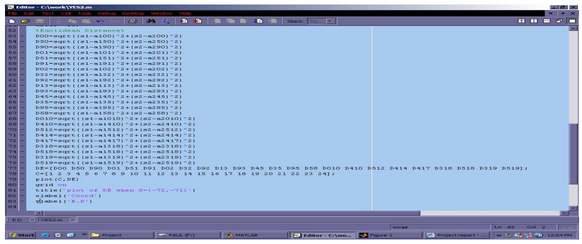

Fig. 8.0 Matlab edit window showing calculations of Euclidean distance (E.D).

Note that the coordinates in Table 1.0 are represented in the above graph as numbers i.e. (0,0) as 1, (5,0) as 2…(5,19) as 24 and also in fig3.2 the alphabet ‘d’ stands for distance, the first digit is the x coordinate of the location, while the remaining digits is the y coordinate . As can be seen in fig3.2, the program shows the coordinates (5,1) and (9,1) have the smallest Euclidean distance and as such either is the closest neighbour and the estimate location of the MS. The ambiguity could result from factors that affect the system accuracy.

Finally, it is worthy of note that for the server of the geolocation system to ‘see’ the MSs, they all have to be networked with the WLAN (this is the complete function of the network administrator). Through this means, the serve ‘sees’ the netstumbler program running in the MSs and an operator at the server can then enter the sample RSS vector values seen are appropriately entered into the matlab program, which is also saved in the server, for the determination of Euclidean distance, as discussed earlier. The flowchart showing the stages in the system is shown in figure 9.

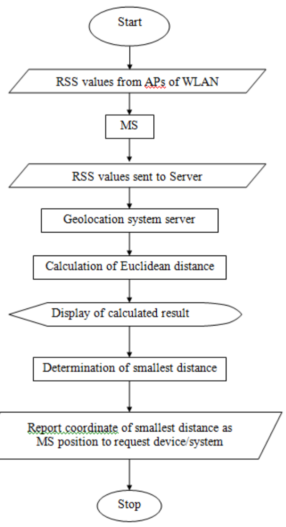

Fig. 9. Indoor geolocation flowchart

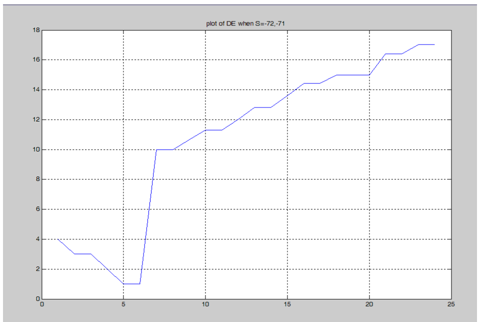

Fig. 10. Matlab graphic window showing a plot of E.D

III. Simulation Results and Mathematical Model

In modelling a system, one tends to translate the operations/function of the system into mathematical formula. The dimension taken in the modelling of this indoor geolocation system is toward the determination of an equation which specifies the output of the system under perfect/ideal working condition. Other models, given as in[9] for example, focuses on analytic modelling – trying to determine the effect on the system, of parameter and radio propagation characteristics such as number of access points, the grid spacing, the path loss exponent and standard deviation. The model and graphical representation in [9] is as follows.

According to [9], the probability that the system returns the

TABLE 2.0 Showing range intervals

Parameter	Value increased	Suggested range
σ –STD. of Gaussian component	pc decreases	σ<4
N- Number of APs	pc increases	3≤N≤5
α- Path loss exponent	pc increases	α>3.5
g- grid spacing	pc increases	g>1.25m

$$\Pr\{C \le 0\} = 1/2 - 1/2 erf(-\mu_c / \sqrt{2\sigma_c}) \qquad (7)$$

where Pr{C≤0} is the probability of correct location estimation out of just two location fingerprints, μ_c is the mean, σc is the standard deviation. It when further to state that they both depend on the difference between the mean RSS at the two locations that is determined by the path loss of the signal [9]. In turn the path loss depends on the site and physical distances of the locations from the N access points and indirectly to the physical distance between the locations [9]. The effect of these parameters using grid spacing, g and the path loss exponent, α was evaluated and described [9].

Still when further to evaluate the probability of returning correctly from multiple average RSS fingerprint(multiple neighbours) but that has not been treated here. Those treated are just for then went further to draw the following conclusion:

As earlier stated in section 3.2 {i.e. formula (3)}, the formula for calculation of Euclidean distance is

$$D_E = \sqrt{\sum_{i=1}^{n} (S_i - a_i)^2}$$

As also stated earlier, the estimate location is that which has the coordinate with the smallest distance. Under a perfect/ideal working condition (baring any possible effects from factors that may affect indoor R_F signal propagation) and where there is no change in the signal strength of the signal from the WLAN[3], sample RSS vector at any particular coordinate should be equal to the average RSS vector recorded in the data base for that coordinate. So, the smallest possible Euclidean distance in the system is 0dBm.[10]

Therefore, under the condition stated above;

$$\sqrt{\sum_{i=1}^{n} (S_i - a_i)^2} \qquad (8)$$

$$\sum_{i=1}^{n} (S_i - a_i)^2 = 0$$

$$\sum_{i=1}^{n} S_i^2 - 2S_i a_i + a_i^2) = 0$$

$$S_i^2 - 2S_i a_i + a_i^2 = 0$$

$$S_i^2 - S_i a_i - S_i a_i + a_i^2 = 0$$

$$S_i(S_i - a_i) - a_i(S_i - a_i) = 0$$

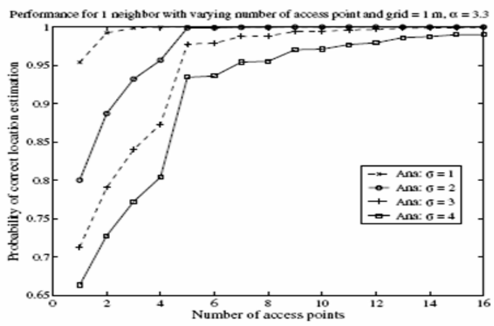

Fig. 11.0. showing the effect of standard deviation on Probability.

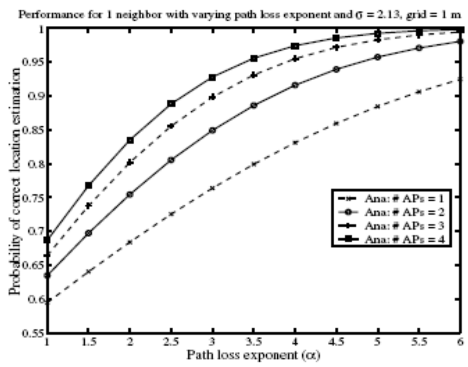

Fig. 11. 2 showing the effect of Path loss exponent on. on Probability.

$$(S_i - a_i)(S_i - a_i) = 0$$

$$S_i = a_i \qquad (9)$$

I= {1, 2…n} n being total number of APs. Equation (8) is simple, yet represents the system equation [5] under perfect working condition. From (6), we state that for the two different signals from the APs; s_1=a_1 and s_2=a_2, since s_i= {s_1, s_2} and a_i= {a_1, a_2}. Plots of (9) will give straight line graphs as

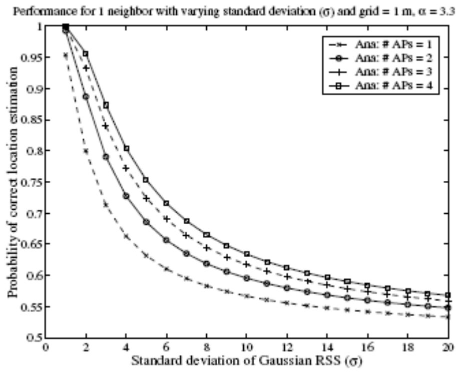

Fig. 12.0 showing the output $s_i=a_i$

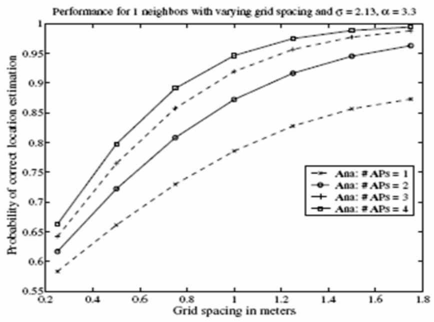

Fig. 11.1. showing the effect of Standard deviation on Probability.

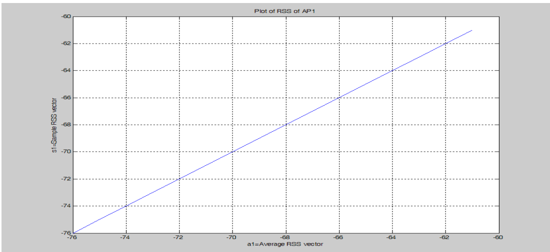

Fig. 11.3 showing the effect of Grid spacing Probability

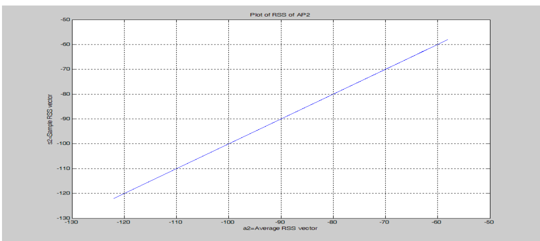

Fig. 12.1 showing output of s2=a2

IV. Conclusions

This work tends to resolve the problem of geolocation within an indoor environment using wireless technology , a technology which for long has been restricted for outdoor environment using GPS. The analysis, simulation and modeling from this work have indicated the following.

There is a great variance between result gotten from mathematical model and simulation result obtain using received signal strength indicator

Mathematical formulae do not give accurate result when analysing signal strength in wireless communication

Received Signal strength indicator (RSSI) remains the only reliable tool for estimating signal

Finally, in conclusion haven gone through the whole processes of this research work, it is worthy of note, that the future of this branch of technology is full of possibilities. The look at the possibility of a totally automated system is a good area for future work. Another direction that is seen wide is the analytic aspect, where the accuracy of the system with respect to location of APs could be investigated The drawback of pattern recognition techniques still lies in substantial efforts needed in maintenance of the signature database in view of the fact that the working environment changes constantly.

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