Comparative Performance Analysis of Different Radio Channel Modelling For Bluetooth Localization System

Idigo Victor.[1] , Okezie C.C[2]Akpado kenneth [3], Ohaneme C.O[4]

[1]Department of Electronics and Computer Engineering, Nnamdi Azikiwe University, Awka
Anambra State(234),Nigeria

[2]Department of Electronics and Computer Engineering, Nnamdi Azikiwe University, Awka
Anambra State(234),Nigeria

[3]Department of Electronics and Computer Engineering, Nnamdi Azikiwe University Awka
AnambraState(234),Nigeria

[4]Department of Electronics and Computer Engineering, Nnamdi Azikiwe University, Awka
Anambra State(234),Nigeria

Abstract

This paper studied the possibility in a Bluetooth network of using channel simulated results as alternatives to on-site measurements and compares the average localization error as a function of a radio map resolution for the free-space path loss wall Attenuation Factor and Ray-Tracer (RT) models. Three reference radio maps were generated; one for each model. The Nearest Neighbour (NN) RSS based localization algorithm was used in this work. This algorithm was applied to the three models with different number of reference points. Results obtained show that RT proved to be more robust technique, especially for grid resolution greater than 10 meters. The simulation results using RT software in these situations is very close to the on-site results. On the other hand, the WAF model produced results that are very close to the on-site results for grid resolution less than 8 meters.

Keywords : path loss, localization, resolution, Bluetooth, Access points

1. Introduction

Position information is essential in many indoor applications. A hospital or health-care facility may wish to be informed of the location of all its patient at all times, a military unit may wish to extend its reconnaissance capabilities beyond the line of sight, a search and a rescue team can locate and provide help quickly if the locations of the individual in distress may be known accurately in advance[1]. Recent indoor applications include mobile e-commerce (m-commerce), e-museums, locating objects in warehouses and big shops(mall), locating books in libraries, etc.

Accurately predicting the location of an individual or an object can be a difficult task producing ambiguous results because of the harsh wireless environment[2]. The harsh site- specific multipath environment in indoor areas introduces difficulties in accurately tracking the position of objects and people. The behaviour of the channel changes from building to building and even within a single floor of a building. The channel may vary with added objects and people moving in the vicinity. As a result, considerable work is needed for modelling the indoor channel for position applications.

Basically, the indoor localization procedure begins with collecting metrics related to the positions of the mobile terminal relative to the reference point. Almost all sort of metrics which are used in telecommunications system can also be used in position estimation systems. Angle of Arrival (AOA) and Received Signal Strength (RSS) are the most popular ones but Time of Arrival (TOA) and Phase of Arrival(POA) can be used as well[3]. The second step is to process the gathered metrics and estimate the location of the desired person or objects. This step usually requires signal processing knowledge unless the finger printing method is used. In using the finger printing method, it is required that a grid-network be built prior to any location estimation. After building the database for a new location, the new metric is measured irrespective of the viewed location and compares it with the database to find the best node, which could be referred to the desired point.

Bluetooth specification [4,5] provides no specific support for positioning service. In the absence of such support, various research efforts have been made in this area with alternating conclusions. The Bluetooth signal strength information has been used to create a system for locating and tracking users inside building[2]. Again, the concept of reference tags and readers that work with both the possibilities of Bluetooth supporting and not supporting the signal strength parameter has also been introduced[6]. However, other works suggest an unreliable relationship between the positioning and the signal strength and hence avoids this parameter for positioning with Bluetooth[7].

The objective of this work is to compare the performance of a Bluetooth indoor localization systems that is modelled using on-site measurements of RSSI values with other channel modelling approaches such as wall attenuation factor and Ray-tracing models.

2. Recent Emerging Indoor Models

In general, indoor channels may be classified either as line-of-sight(LOS) or obstructed (OBS), with varying degree of clutter. Some of the key models which have recently emerged are presented below.

- Partition Losses(Same Floor).
  Buildings have a wide variety of partitions and obstructions which form the internal or external structure. Partitions that are formed as part of building structure are called “ hard partitions”, and partitions that may be moved and which do not span to the ceiling are called “ soft partitions”. Partitions vary widely in their physical and electrical characteristics making it difficult to apply general models to specific indoor installations. Average signal loss measurement obstructed by common building material is given in [3].
- Partition Losses between floors

The losses between floors of a building are determined by the external dimensions and materials of the building, as well as the type of construction used to create the floors and the external surroundings[3]. Even the number of windows in a building and the presence of tinting(which attenuates the radio energy) can impact the loss between floors.

- Log distance path loss model

  Indoor path has been shown by many researchers to obey the distance power law as shown in equation (1) [3]:

$$PL(dB) = PL(d_0) + 10\alpha\log(d/d_0) + X\sigma \quad (1)$$

  Where α = path loss exponent which indicates the rate at which the path loss increase with distance and depends on the surroundings and building type, and $X\sigma$ represents a normal random variable in dB having a standard deviation of σ dB. d_0 is the close- in reference distance which is determined from measurements close to the transmitter while d is the transmitter-receiver distance.

- Attenuation Factor Model

  This model provides flexibility and was shown to reduce the standard deviation between measured and predicted path loss to around 4dB, as compared to 13dB when only a log-distance model is used in two buildings[2]. The attenuation factor model is given by[3,8]

$$PL(d)\ [dB] = PL(d_0)\ [dB] + 10\alpha_{nf} \log(d/d_0) + FAF[dB] + \sum PAF[dB] \quad (2)$$

  Where α_{nf} = the exponent value for "same floor" measurement, FAF = floor attenuation factor for a specific number of building floors and PAF = Partition attenuation factor for a specified obstruction encountered by a ray drawn between the transmitter and receiver.

- Wall Attenuation Factor (WAF) Model

  This model was proposed in [9], which included attenuation factor for building floors to disregard the effects of floors and instead consider the effects of obstacles(walls) between the transmitter and receiver. The wall Attenuation factor (WAF) model is described by[2,3]:

$$P(d)\ [dBm] = P(d_0)[dB] + 10\alpha\log(d/d_0) - \begin{pmatrix} nW.WAF, nW < c \\ c.WAF, nW \geq c \end{pmatrix}$$

  Where α = path loss exponent that indicates the rate at which the path loss increases with distance, $P(d_0)$ = the signal power at some reference distance d_0 , d = transmitter- receiver separation, C = the maximum number of walls up to which the attenuation factor makes a difference, nW = the number of walls between the transmitter and the receiver, WAF = the wall attenuation factor.

- Channel Modelling using Ray Tracer

Ray – Tracing (RT) is a simulation tool encompassing the geometrical information of a floor plan in addition to the reflection and transmission coefficients of building materials that models the radio channel behaviour in different areas [10]. For a pair of transmitter-receiver at some known locations, RT determines the necessary information of a channel such as arrival angle, departure angle, phase, number of reflections and number of transmissions by sending a set of rays from the transmitter and tracing them until they either reach the receiver or largely attenuated that they can not be detected by the receiver. The TOA, magnitude, and phase of each path are recorded for each ray.

The predictions from ray tracing software are partition largely accurate for propagation of radio signals at frequencies greater than 900MHZ where electromagnetic waves can be described as travelling along localized ray paths. This method is shown to be accurate for indoor environments[3,10]. RT can be used to produce large database of channel impulse responses for statistical analysis of the channel. Therefore, RT is a viable alternative to physical measurements.

3. Methodology

Three reference radio maps were generated for on-site measurement, WAF and RT channel models. The nearest neighbour (NN) algorithm was used as the localization algorithm. The experimental test bed is the Electronic and communications laboratory of Nnamdi Azikiwe University, Awka, Nigeria. The test bed was segmented by a square of 1x1 meters as shown in figure 1. A Pentium based laptop equipped with Bluetooth device was placed at positions shown in the test bed. The mobile host carried by the user being tracked, was another Pentium based laptop equipped with a Bluetooth devices.

The protocol stack used in this equipment was provided by the Bluetooth simulator(BlueHoc). BlueHoc is IBM's new Bluetooth simulator released under IBM public license. It allows one to evaluate how Bluetooth performs under various ad-hoc scenarios.

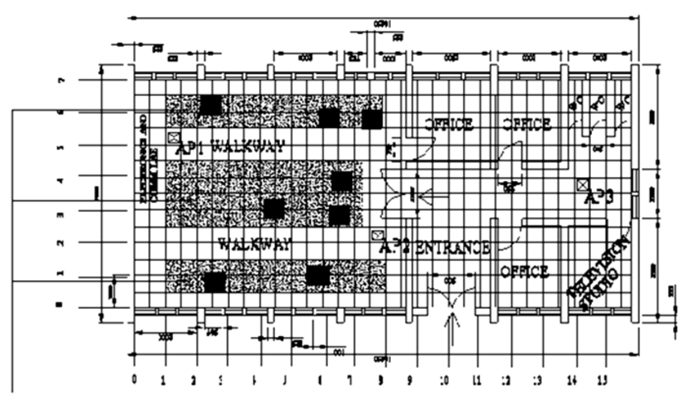

Figure 1 : Experimental Test bed

3.1 Channel characterization using on-site measurements.

A total of 75 RSSI data sets were collected from a square grid of 25 positions in the test bed. First, the measurements were carried out using one transmitting Bluetooth, then two and finally three. At any given location, the RSSI measuring laptop(MS) can receive signals from transmitting Bluetooth. Each set of measurements consists of five minutes at approximately 0.25 second sampling interval. That is approximately 1200 data points were collected for each set. A sample measurement of RSSI data collected from transmitting Bluetooth is shown in figure 2

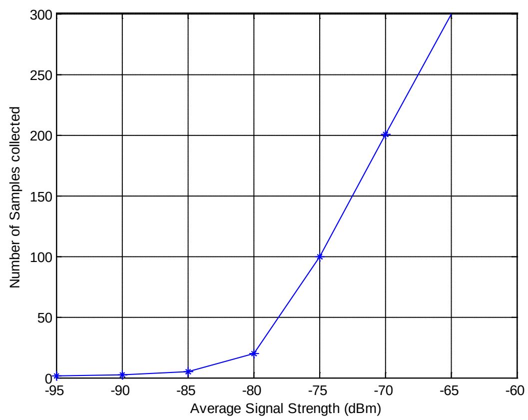

Fig. 2 Analysis of RSSI measurements over 5 minutes

3.2 Channel Characterization using WAF models

Two experiments that leads to the determination of WAF were conducted. First several measurements were taken to show the distribution of signal strength as a function of T-R separation derived from the empirical data collected in the off-line or data collecting phase. Secondly, experiments were conducted to determine the WAF. Finally, the effect of applying correction for intervening walls between the station and the mobile user was shown

Figure 3 illustrate how the average signal strength at each point varies with distance between the transmitter and also the receiver. The wide difference in signal strengths between points at similar distances is explained as follows: the layout of the rooms in the building, the placement of the base station and the location of the mobile user all have an effect on the received signal. Signals transmitted may be attenuated by different amounts due to the difference in the number and types of obstructions they encountered. For instance, in Fig. 3 , it was observed that the strength of the signal from two locations approximately 1.5meters from the base stations were approximately 8dBm apart. This is because there were several wall between one of the locations and the base stations, while the other locations had line-of-sight to the station.

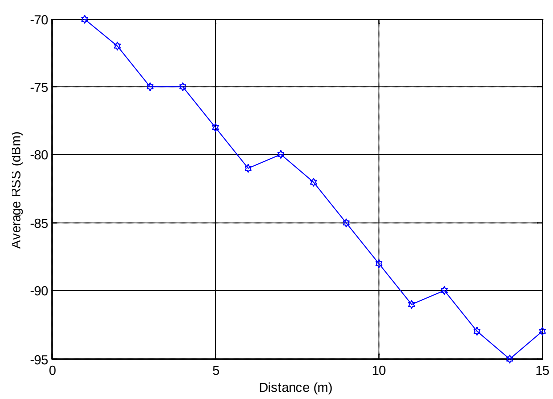

Figure 3: Average RSSI (dBm) versus Distance(m)

Furthermore, the following experiment was conducted to determine the wall Attenuation factor (WAF): first the measurement of the signal strength at the receiver when the receiver and the transmitter had line of sight was taken . Then the signal strength measurement with varying but known number of walls between the receiver and the transmitter (n=1,2,3,) were taken. Computation of the average of the difference between the signal strength values was used to determine the WAF. Fig. 4 shows the WAF graph obtained from this experiment for n = 1(WAF1), n = 2 (WAF2), and n = 3 (WAF3).

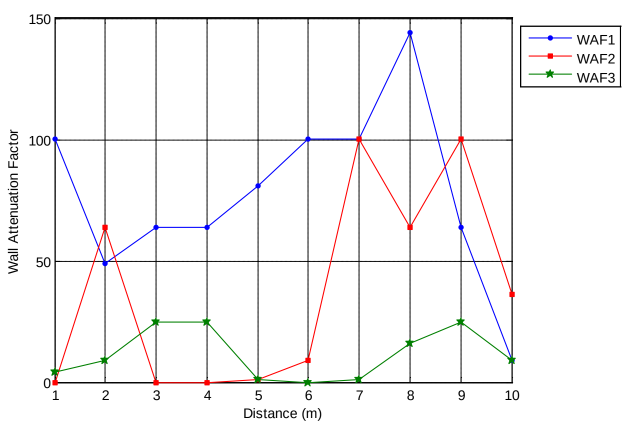

Figure 4 :Wall Attenuation Factor Graph

It is observed that the amount of additional attenuation dropped off as the number of walls separating the transmitting Bluetooth device and MS increased. Based on Measurements, we choose WAF to be 3.0dBm and C to be 4 (where C represents the number of walls that are factored into the model).

Figure 5 shows the results after the measured signal strength has been compensated for signal loss due to the intervening walls between the transmitting Bluetooth device and MS. This figure also shows a trend similar to that of the free-space loss(fig.3). This demonstrates that WAF propagation model compensates effectively attenuation due to obstructions.

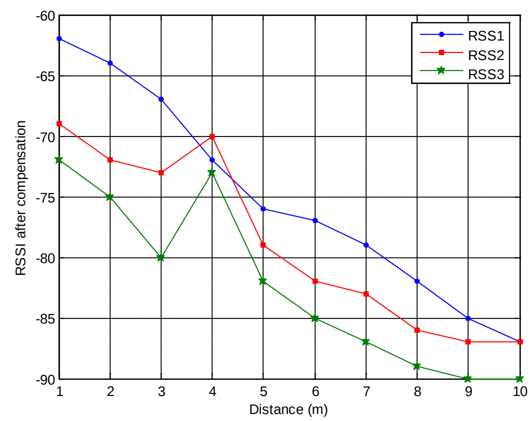

Figure 5 :Average RSS values after compensation

3.3 Channel Characterization using RT model

Figure 6 shows a typical channel impulse response generated by RT in the left side of the test bed . This model contains all the geometrical information of the floor plan such as doors and windows .

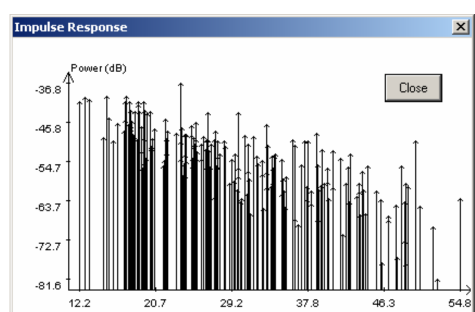

Figure 6: A channel impulse response generated by RT

4. Comparative Analysis of On-Site measurement(free space loss), WAF and RT models

4.1 Experimental Setup

The performance of the empirical free space loss model was compared with the results from WAF and RT models. The objectives are to :

- To study the possibility of using channel simulated results as alternative to on – site measurements.
- To compare the average localization error as a function of a radio map resolution for the three models

Major components of the experiment are shown in figure 7. Three reference radio maps were generated for on-site measurement, WAF and RT channel models. The nearest neighbour (NN) was used as localization algorithm.

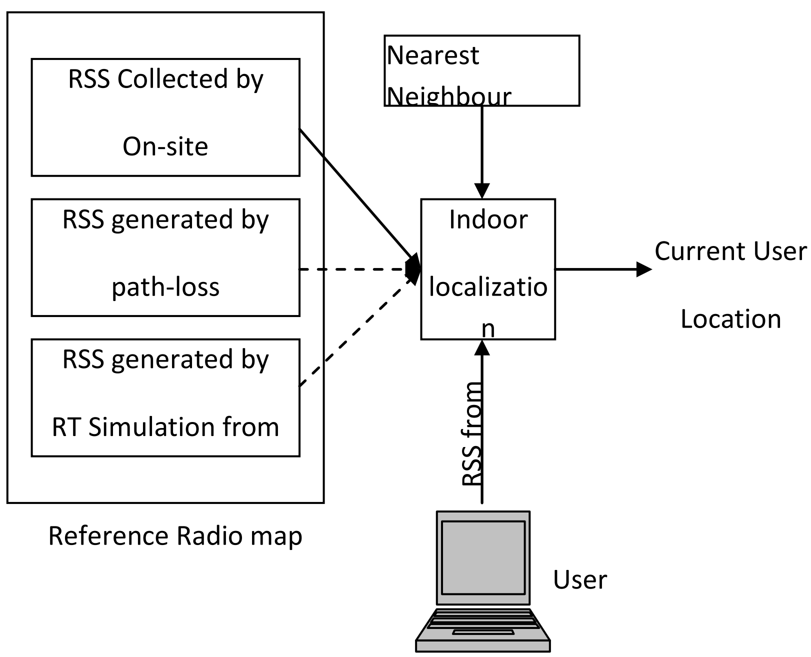

Figure 7 : Major Components of the comparison Test bed

4.2 Results and Discussion

An important performance metric in a positioning system called localization error was used. This depends on the resolution of the reference radio map. As shown in [6], the performance of a typical localization algorithm can be improved by using a finer grid of reference points. Figure 9 shows the impact of the number reference points in the distribution of localization accuracy in a system using the nearest neighbour algorithm on the three models: Increasing the number of reference point from 4 to 250 reduces the ninety percentile (P_{90}) of the localization error from 20 meters to 5 meters.

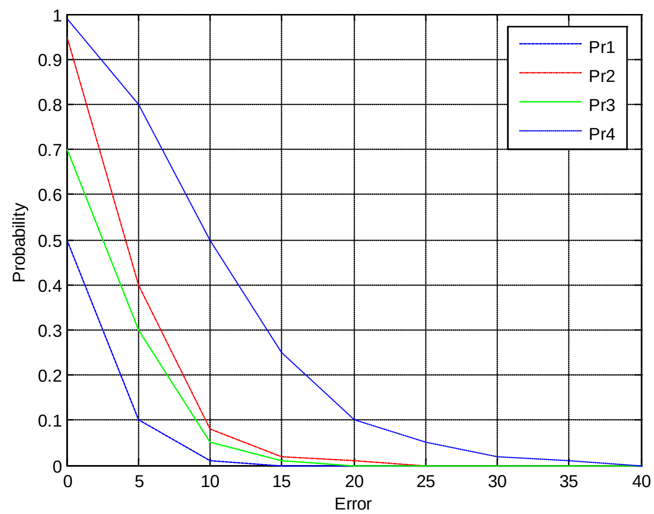

Figure 8: Impact of number of reference points on localization error using NN algorithms

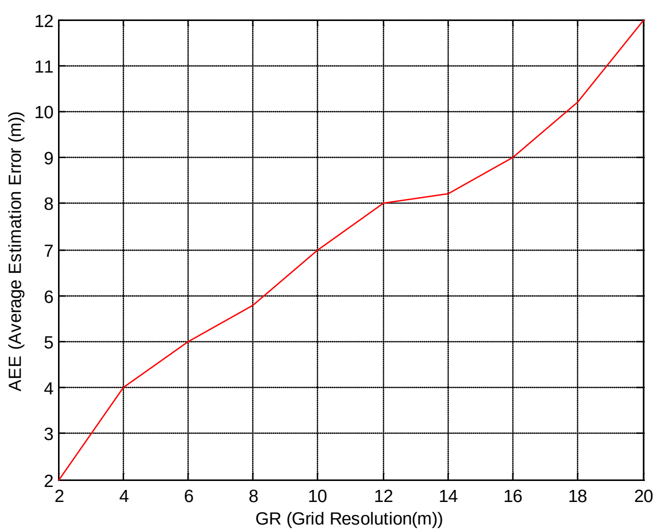

Figure 9 (a)

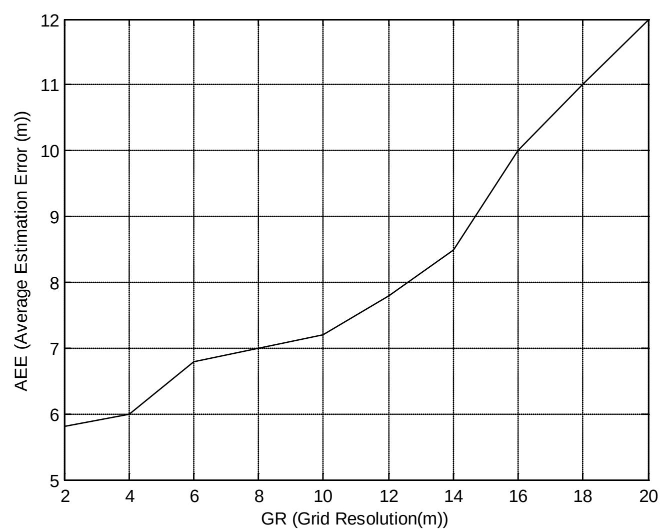

Figure 9 (b)

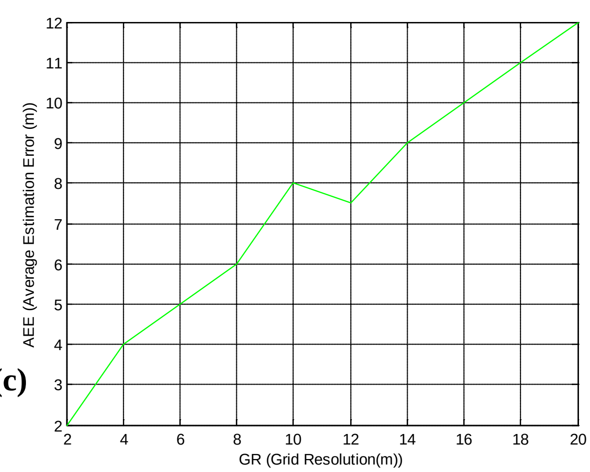

Figure 9 (c)

Figure 9: Average localization for the three models

(a) for a system trained with on-site measurement

(b) for a system trained with RT Channel Simulator

(c) for system trained with WAF model

Figure 9 (a-c) shows the average distance error estimation with NN algorithm as a function of grid resolution for the three radio maps. Using these curves, a system designer can determine the optimum number of reference points to achieve a desired localization accuracy which is dictated by the application requirements. From these plots it can be seen that the performance of an RT trained RSS based localization system is comparable to a system which is trained by an on-site measurements. For example, NN algorithm in a system which uses a RT generated reference radio map with 10 meter grid resolution is 7.2 meters which is a good approximation for the corresponding value of 7.0 meters for the case of on-site mode for any practical deployments.

Between the WAF and RT modelling approaches, RT proved to be more robust technique(especially for grid resolution> 10 meters). The simulation results using RT software in these situations is very close to the on-site results. On the other hand, the WAF model produced results that are very close to the on-site results for grid resolutions < 8 meters.

Using the RT modelling technique, we can easily increase the grid resolution to achieve higher localization while increasing the number of reference points using on-site measurements is a real challenge. In both WAF and RT modelling technique, the system needs to know the exact locations of the transmitting Bluetooth device in order to create the reference radio map. However, a positioning system trained with on-site measurement does not require knowing the location of the transmitting Bluetooth device.

5. Conclusion

This work compares the performance of a Bluetooth indoor localization systems that models the radio channel using RSSI values obtained from on-site measurement, WAF, and RT models. Three reference radio maps were generated for on-site measurement using free-space pathloss, WAF, and RT models. The NN algorithm was used as the localization algorithm.

An important performance metric for accessing the performance of positioning system called the localization error was used in accessing the models. This metric depends on the resolution of the reference map. The performance of the localization algorithm was found to improve by using finer grid of reference points. Finally, the study showed that using channel simulated results can be an alternative to on-site measurements.

References

[1]. Kiran thapa, and steven case , (2006) , “An Indoor positioning service for Bluetooth Ad-Hoc Networks”, Department of computer and Information Science, Minnesota state university Mankato< www.mnsu.edu>

[2]. Kamol K. And Prastiant K. (2004), ” Modelling of indoor positioning system based on location fingerprinting”, School of information science, university of Pittsburgh publications. pp 15-23.

[3]. Rappaport, T.S. (2003), Wireless Communications, Pearson Education Inc, India

[4]. Bluetooth special Interest Group (2001), ” Specification volume 1, specification by Bluetooth system, core” version 1.1, SIG. 18^{th} Feb. 2006. <www.bluetooth.com>

[5]. Bluetooth special Interest Group (2001),” Specification volume 2, specification by Bluetooth system, profiles” version 1.1, SIG. 18^{th} Feb. 2006. <www.bluetooth.com>

[6]. Bahl, P. And Padmanabham, V. (2000), “RADAR: An In-Building RF-Based user location and tracking system” Proceedings of IEEE infocom 2000, Tel-Aviv, Israel, Vol 2, pp 755-784

[7]. Patil, A. (2002), “ Performance of Bluetooth Technologies and their applications to location sensing”, Michigan state university publications, 4^{th} edition , pp 15-25

[8]. Moustafa, P. 22^{nd} Sept. 2007. <www.moustafa.usv.edu>

[9]. Orino. 10^{th} Jan. 2008. < www.orinocowireless.com>

[10]. Spiros D. Mantis (1999), “ Localization of Wireless Emitters Using Time Difference of Arrival (TDOA) methods in Noisy Channels” Masters thesis Naval PG school Monterey, California.