*JWSN* 2016, 3, 1-0015

*Journal of Wireless Sensor Networks*
**ISSN: 2001-6417**
www.wsn-journal.com

*Article*

# ANALYSIS AND ESTIMATION OF TIME OF ARRIVAL AND RECEIVED SIGNAL STRENGTH IN WIRELESS COMMUNICATION FOR INDOOR GEOLOCATION

Okeke Benjamin Chukwuejekwu[1], Lazarus Okechukwu Uzoechi[2],.James Agajo[3] ,Okpe Godwin[4] Kabis salisu Danja[5]

[1]Department of Information Management Technology, Federal University of Technology Owerri Imo Nigeria

[2]Federal University of Technology, Dept. of Electrical/Electronic Federal University of Technology Owerri Imo State Nigeria

[3]Department of Computer Engineering Federal University of Technology Minna Nigeris

[4,5]National Board for Technical Education , Programmes Department Kaduna Nigeria

*email: agajojul@gmail.com*

*Received: 11th December2015 / Accepted: 30th December 2015/ Published: 21st January 2016*

---

***Abstract:*** *Analysis and estimation of the time of arrival and received signal strength for indoor geolocation using MATLAB describes an indoor geolocation localization which either use the received signal strength (RSS) or time of arrival (TOA) of the received signal as their localization metric. Though time of arrival based systems are sensitive to the available bandwidth and also to the occurrence of undetected direct path (UDP) channel conditions which RSS based system are less sensitive to the bandwidth as more resilient to undetected conditions. This paper demonstrate the availability of radio channel modeling techniques to eliminate the costly finger printing process in pattern recognition algorithms by introducing ray tracing (RT) assisted by RSS and TOA based algorithms. The results shows the effect of pathloss on signal reception, showing free path loss reduces when plotted with the height of the building which can be used for achieving localization. It was also discovered that path loss also contributes to signal delay and the RSS at fixed positions can be used to determine geolocation.*

**Keyword: Access Point; RSS; Localization; TOA ; Geolocation.**

---

## 1. INTRODUCTION

Localization using radio signals was first introduced in world war II to locate soldiers in emergency situations. During the war in Vietnam, the Global Positioning System (GPS) was introduced. This system became available for commercial applications around 1990.

The commonly used approaches for measuring position estimate in WSN are Time of Arrival (TOA) [15], Time Difference of Arrival (TDOA)[11], Received Signal Strength (RSS)[10,11] and Angle of Arrival (AOA) that is, Direction of Arrival (DOA)[18]. Where, the TOA, TDOA, and RSS measurement gives the distance calculation between the source node and the receiver node while DOAs provide the information of the angle and the distance

measurements from the source and the receiver. Calculating these distance and angle measurements is not simple because of the nonlinear relationships with the source. [11]
Given the TOA, TDOA, RSS and DOA information, the main focus of this paper is based on TOA positioning algorithms. We consider a two dimensional (2D) rectangular area where the sensors are deployed in Line-of-Sight (LOS) transmission, i.e., there is a direct path between the source and each receiver [19]. Also, we conclude that the measurements are well inside the expected range in order to obtain reliable location estimation.[11]

## 2 LOCALIZATION

A network infrastructure deployed to determine the relative coordinates of a mobile-station (MS), with respect to some known reference location (reference-points); is known as a wireless positioning system.

For example, a global-positioning-system (GPS) receiver determines its relative location with respect to a set of reference satellites and converts that locations to a set of latitude, longitude, and altitude values.
Positioning systems can be deployed as an overlay service on top of the access network infrastructure localization is the process of acquiring the location of mobile station (MS) from a positioning system. This process is also referred to as positioning , geolocation [1], and location sensing [10].

## CHANNEL BEHAVIOUR AND INDOOR LOCALIZATION

During localization, the Mobile Stations localization is estimated by comparing the desired signals with the existing fingerprints in the radio map. In pattern algorithm localization, the radio is an integrated component of the algorithm.

A more accurate radio map can provide a better localization performance. However, RF finger-printing using on site measurements is a time consuming process and a drawback for in , it is ideal to replace this procedure.
As shown in figure (1), Wireless LAN area network (WLAN) terminology is used, in which an access-point (AP) provides the connectivity between a Mobile Station (MS) and the network infrastructure, access-points (APs) are the only entities which transmit localization information [4].

## 2.1 DISTANCE BASED ALGORITHMS

The distance based algorithms uses the estimated distances between the Mobile Station (MS) and at least three referencing points in a process called triangulation to find its location [figure 1].
Note: Triangulation is a method for determining location trigonometrically, that is a navigation technique that uses the trigonometric properties of triangles to determine a location or course by means of compass bearings from two ports a known distance. In an ideal channel, the actual expected and the estimated DP(Direct Path) are the same.

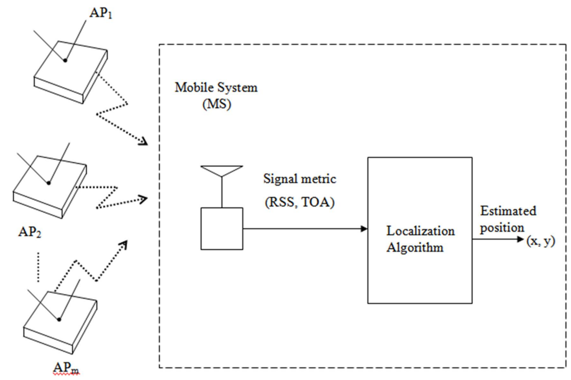


**Figure 1 A Typical positioning System.**

However, in multipath conditions as shown in figure 7, the peak of the channel profile shifts from the expected time of arrival resulting in a time of arrival estimation error caused by the multipath condition. This ranging error is referred to as distance-measurement error (DME), which is defined as the error caused by erroneous estimate of the time of arrival and it is given by

$$\epsilon_{d_w} = / \, d_w - d \, / \qquad \text{.......................... 1}$$

## 2.2 THREE CLASSES OF BEHAVIOUR

Wideband channel profiles are classified into
(a) Dominant-direct-path (DDP),

(b) Non-dominant-direct-path (NDDP)<
(c) Undetected-direct-path (UDP) categories [5].

In a DDP channel profile direct-path (DP) which is the strongest path in the profile can be detected by the receiver.

In NDDP channel profiles the direct path (DP) is not the dominant path of the channel impulse response, however, DP can be detected by a more complex receiver.

In UDP channels direct path goes below the detection threshold of the receiver while other paths are still detectable, the receiver assumes the first detected-path (FDP) as direct path (DP) which causes large distance-measurement error (DME) values.

The accuracy of time of arrival estimation depends on the system bandwidth [5].

### 2.3 WIRELESS FIDELITY (WiFi) RSS MEASUREMENT SYSTEM

Most of the shelf WiFi devices are able to measure RSS from the available access points (APs). Figure 3 shows the major components of this measurement system. A linksys 802.11b/g access point (AP) at a known location is used as a transmitter in a designated channel.

Since most existing positioning systems use the information provided by the wireless LAN area network (WLAN) interface and a laptop computer equipped with a dual proxim 802.11PC card are used as the receiver.
There are two alternative options for communicating with an access-point (AP).
In the first alternative, the receiver (an 802.11 card) in a process called active scanning, periodically broadcasts a proof request frame, listens for probe responses from available access-points in its neighborhood and records the associated signal strength.
The second alternative is passive scanning in which the receiver shifts each of the available 802.11 channels periodically to discover the received signal strength (RSS) value since an access point can be configured not to respond to broadcast probe requests and there is no restricting assumption about the wireless local Area Network (WLAN) deployment, passive scanning is used while relying on the existence of a beacon from each aces point.

An IEEE 802.11b WLAN AP broadcasts a beacon on an assigned channel in the 2.4GHZ band every 10 miliseconds to report network availability as well as link quality information. The 2.4GHZ band is shared by other equipment in the industrial-scientific-medical (ISM) band. This band is divided into channels 1 – 11 each with 26MHZ of bandwidth with three non-overlapping channels.
The link level information available in each beacon frame includes the access points (AP's) name, access-points medium-access-control (MAC) address, received signal strength (RSS) in dBm, noise in dBm, signal-to-noise ratio (SNR) in dB and channel number.

There are many factors affecting the wireless LAN area network (WLAN) based RSS measurements such as:
(a) Mobile station's orientation,
(b) Time of the day,
(c) Environment
(d) Distance from transmitter,
(e) Interference from other access-points (AP)

A dedicated channel is usually used for measurements to limit the effect of interference from other AP's in the area. In order to address the mobile station's orientation factor, the measurement is done in multiple directions at the same location.
The post processing unit is used to extract the information associated with the desired access-point and add a time lay and apply a five seconds averaging window to the collected data.

At the end it should note that RSS values reported by most WLAN cards are in integral steps of one dBm consequently not all possible RSS values can be represented and the measurement results are dependent on the sensitivity of the WLAN card. The sensitivity of some typical WLAN cards is reported in table (1) [2].
A sample path loss model and a line of site path and a simple RSS distribution at fixed location obtained with this measurement system are depicted in the figures below.

**Table 1: Measurable range of WLAN cards.**

| Vendor | Model | Max RSS (dBm) | Min RSS [dBm] | Range [dB] |
|---|---|---|---|---|
| Lucent | Orinoco Gold | - 10 | -102 | 92 |
| Lucent | Wave LAN silver | - 10 | -94 | 84 |
| Cisco | Aironet 350 series | -10 | -117 | 101 |
| Proxim | Orinoco Gold | -11 | -93 | 82 |
| SMC | EZ connect SMC2635W | -14 | -82 | 68 |
| D-link | Airplus DWL-650+ | -50 | -100 | 50 |

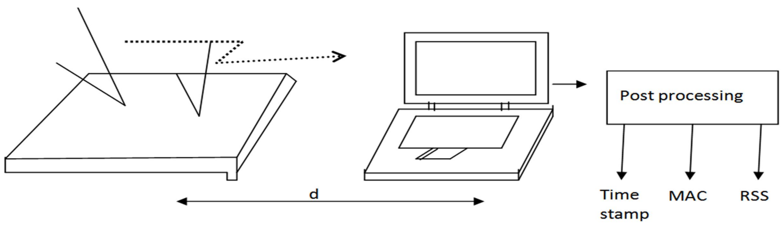


**Figure 3: RSS channel measurement system for indoor localization**

In the path loss shown in figure (4), the observed distance power gradient is ∝ = 2.1 which is similar to a LOS condition. the statistical distribution of the temporal behaviour of RSS at a fixed location is depicted in figure (5).

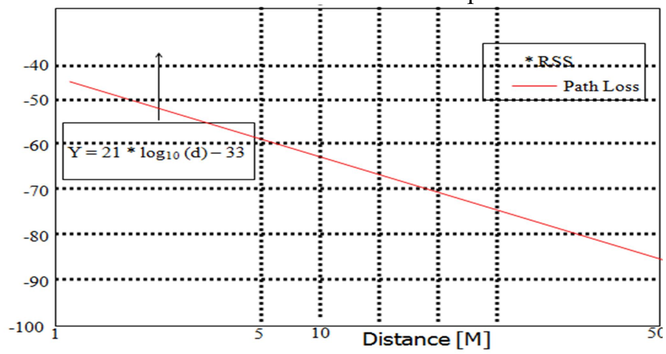


**Figure 3: Sample path loss measured by IEEE 802.11 pc Card**

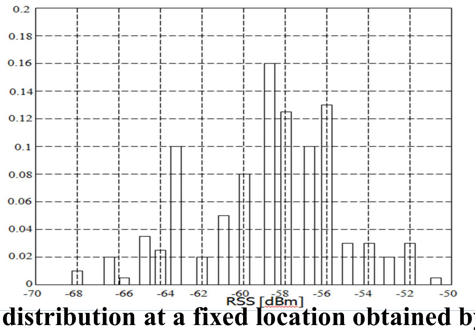


**Figure 4: RSS distribution at a fixed location obtained by a WiFi measurement system.**

## 2.4 UWB MEASUREMENT SYSTEM

Although RSS measurement system provides a convenient and easy to implement measurement system, it does not provide channel impulse response which is required for development of more complex TOA and RSS based localization algorithms.

This work hereby describes how wideband frequency domain measurement system that determine the channel impulse response by sending a narrow pulse and observing the effect of the channel on the received signal [5, 9]. The major components of the coherent wideband frequency domain measurement system are shown in figure (5).

The wide band network analyzer emulates a coherent transmitter-receiver set. A short duration pulse is generated as a frequency sweep by the network analyzer and transmitted over the air through the transmitter antenna after RF power amplification. The transmitted signal arrives at the receiver antenna, passes through a low noise amplifier and appears at the input of the network analyzer.

Since transmission of a band-limited signal results in a long duration pulse in the time domain, in order to achieve better spectral characteristics, a raised cosine window with 50 percent excess bandwidth (β = ½) is applied to the transmitted signal.

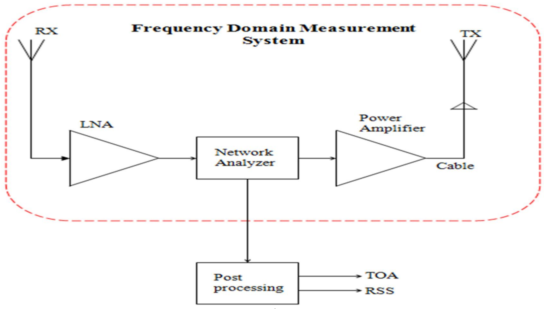


**Figure 5: Frequency domain measurement system**

## 3 TWO CLASSES OF LOCALIZATION ALGORITHMS

An indoor positioning system estimates the location of the Mobile System (MS) by using some signal metrics from a number of AP's distributed in the area in a process called localization.

This is classified into distance based algorithms or pattern recognition based methods. A distance based localization algorithms determine the distance between MS and three or more reference points; which may or may not be collocated with the AP's; and locates MS through triangulation. In pattern recognition based algorithms, the localization system gets off-line training to create a reference database of possible locations in an environment with an associated finger print at this location.

- Localization Algorithms
  - Distance Based
    - TOA
    - RSS
    - Hybrid RSS-TOA
  - Pattern Recognition
    - TOA
    - RSS
    - Hybrid RSS-TOA

**Figure 6: Classification of localization algorithms.**

Recognition algorithms use on site measurements to create the required reference radio map.

A distance based localization algorithms determines the distance between mobile station (MS) and each AP and locates MS through triangulation. The distance can be estimated from the alternation of signal strength based on path loss, angle of arrival (AOA), time of arrival, and time difference of arrival (TDOA) of a signal. Distance estimation using TOA, DTOA, and AOA has been studies extensively for outdoor positioning system [2].

These techniques are suitable for non-undetected direct path (NUDP) conditions. However, they suffer from large errors in indoor environments with undetected direct path (UDP) conditions. In practical system analysis with limited bandwidth 10, the received signal $r^{w}{}_{d}$ is given by:

$$r^{W}d\ (t) = \int_{-\infty}^{+\infty} X_w\ (\tau)h_d\ (t - \tau)\ d\tau \text{ --------------------}2$$

Where $X_w(t)$ is the transmitted pulse. In a TOA based system the receiver estimates the distance between the transmitter and the receiver ($d_w$) by extracting the first detected peak (FDP) of the channel impulse response by applying:

$d_w = C \text{ x } C_1W$ -------------------- (3) the error in distance estimates is quantified by distance measuring error DME defined as:

$E_{d.w}$=/dw – d/

Where d represents the actual distance between the transmitter and the receiver.

TOA based distance estimation suffers from additive noise, and multipath effect, causes UDP conditions, which can generate large range errors especially in systems with less bandwath [3].

For short range measurements where direct path exist DME is statistically determined by Gaussian (N(Cμ,C2σ2) where μ and σ2I are the mean and the variance of the TOA estimation error[6]. However, UDP cases generate large errors that to not follow a zero mean Gaussian distribution [8].

Distance estimation using TOA of a signal has been used in commercial products with good precisions under NUDP conditions in wideband systems. A typical localization algorithm which applies triangulation using distance estimation is least square TOA (LS-TOA).

In general, the relationship between the average power in dB, RSS, and distance d is given by [9]:

$$RSS_d = P_t - 10\alpha\log_{10}d + X \qquad \text{------------------}(4)$$

In which $\alpha$ is the distance – power gradient, X is the shadow fading $N(O, \sigma^2{}_x)$, and $p_t$ is the transmitted power in dB.

### 3.1 PATTERN RECOGNTION BASED LOCALIZATION

In recent years, pattern recognition techniques have been used for indoor localization as an alternative to distance based algorithms since distance estimation in a multipath and scatter rich environment is a challenging problem. In pattern system gets off-line training to create a reference database of possible locations in an environment with an associated fingerprint at those locations.

This pre-generated database is referred to as reference radio map. During the localization period, the matching algorithm compares the characteristics of the observed signal with the existing finger print in the radio map and chooses the reference point that matches best with the observed data and declares that as the mobile system's current location.

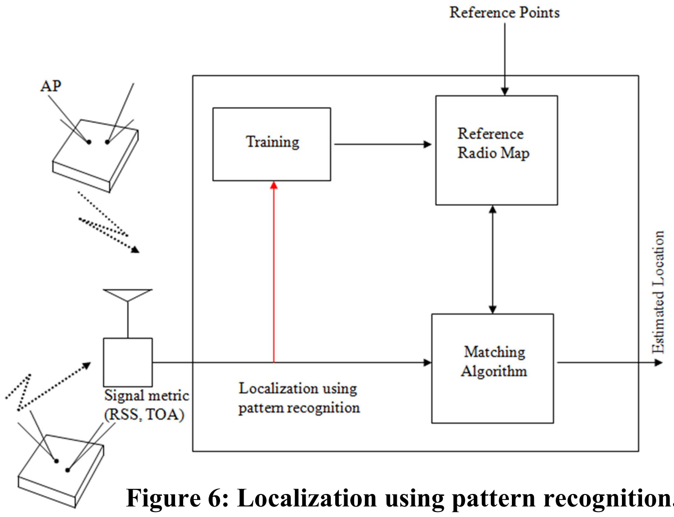


**Figure 6: Localization using pattern recognition.**

### 3.2 TIME OF ARRIVAL BASED LOCALIZATION

There are two short comings with current RSS based localization techniques. The first limitation is caused by the fact that RSS based systems do not use the physical characteristics of the signal directly and rely on an environment dependent radio map which needs to be generated and calibrated for each and every building thus RSS based algorithms are restricted inside a building area, and do not scale well for large service area.

The second short coming of RSS based algorithms low accuracy. In mission critical applications such as public safety, patient tracking, etc. the positioning system must be able to find the location with an estimation error of less than 1-5meters in indoor areas.

In order to achieve such a high accuracy, the localization algorithm must rely on other signal metrics such as TOA of a signal.

### 3.3 BEHAVIOUR OF TIME ARRIVAL ESTIMATION

The direct line-of-sight (LOS) path between transmitter and receiver antennas is defined as the direct-path (DP), and time of arrival (TOA) of this path indicates the distance between the transmitter and the receiver.

In time of arrival based indoor geolocation systems, the first detected peak of the channel profile is used above a detection threshold as the estimated time of arrival of the direct path, this is called first-detected-peak (FDP).

The time of arrival (TOA) of first-detected-peak (G, W) is an estimation of time of arrival of the direct-path, ($^{+}$DP).

Thus, the estimated distance between the transmitter and the receiver antennas are obtained from

$dw = c \times C_1, w$ ------------------------ (5)

Where c = the speed of light

W = bandwidth

$\tau_{pp}$ = time of arrival of DP

$C_1W$ = TOA of FDP

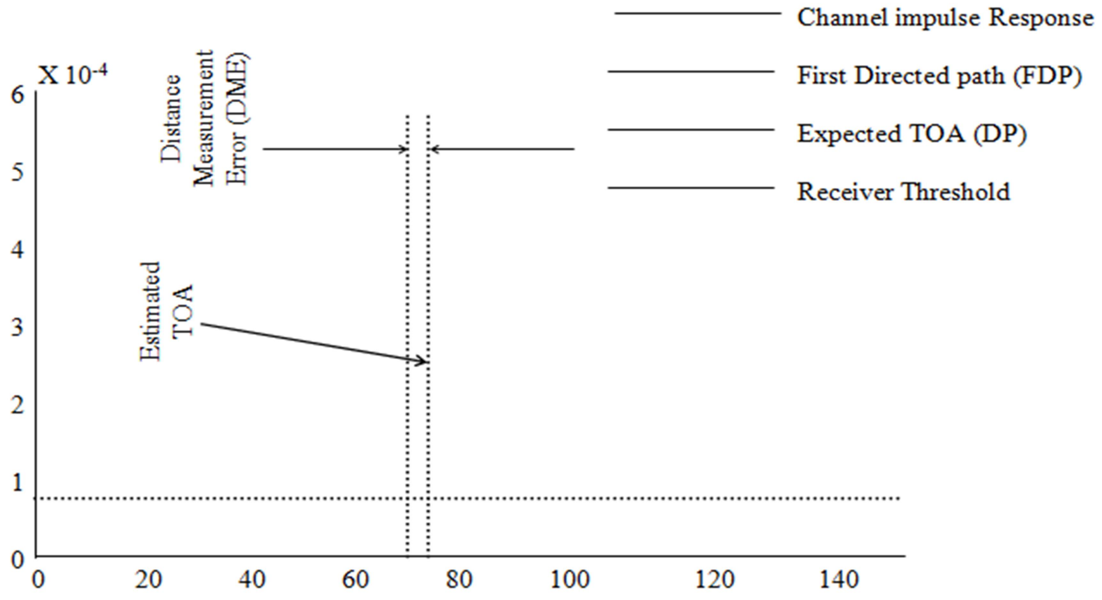


**Figure 7: A sample channel impulse response for a 200MHZ system.**

**4. SIMULATION RESULTS**

Results: The plots below in figure 8 shows the various results and the effect of path loss on signal reception and as well tries to present an appropriate design model for a better signal reception.

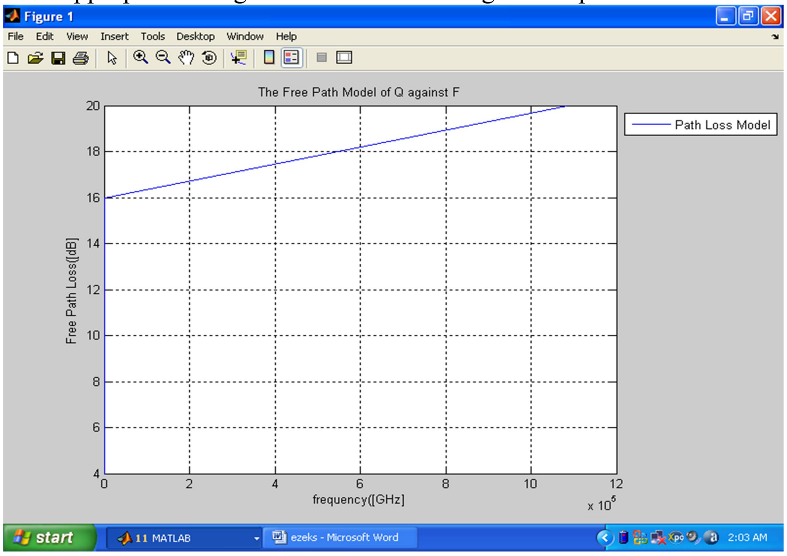


**Figure 8 The plot of free path loss versus Frequency**

The plot in figure 9 shows the effect of free path loss as the frequency increases. From this plot, it can be seen that as the frequency of the signal propagation increases the path loss the signal will encounter along the line of propagation will also be increasing. Thus, path loss is an undesirable effect in transmission of signal therefore, it must be eliminated.

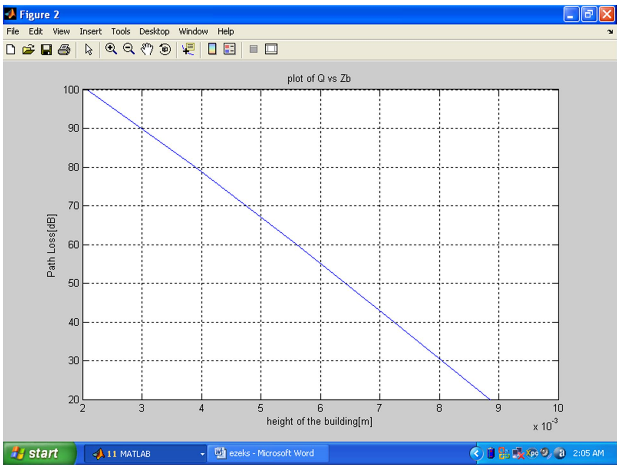


**Figure 9 The plot of Path loss against Building height**

This plot in figure 9 above shows that as the height of the building increases the path loss will as well be increasing, just as the path loss increases as frequency increases. This account to some of the challenges faces the research on indoor geolocation systems. Because an accurate signal reception need to be received to enable emergency personnel to locate victims in case of any eventuality. Example, if there is an out-break of inferno in a high rise building, the fire fighters need an accurate reception of signal to enable them to navigate in such buildings and performed the rescue operation successfully.

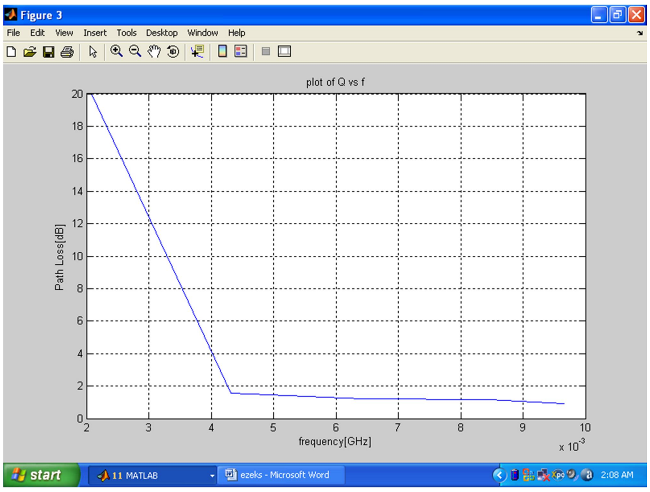


**Figure 10 Path loss against Frequency**

This plot in figure 10 depicts what an ideal system should look like. Because in communication technology, signal throughput is of very important. This plot shows that as the frequency increases, it will be seen that the effect of path loss is decreasing up to the point that its effect will not be much noticed.

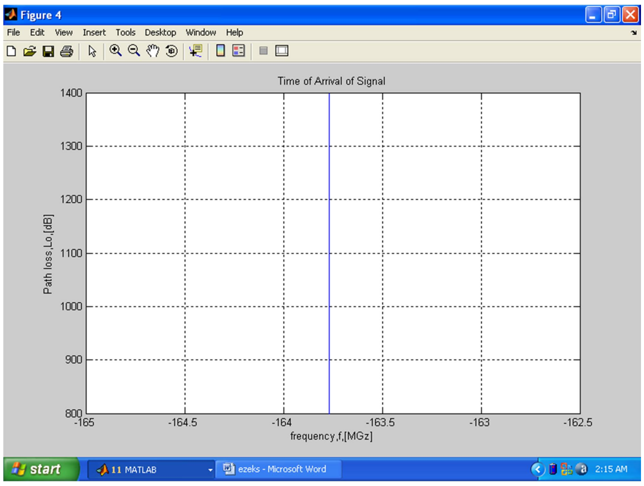


**Figure 11 Time Arrival Estimation**

This plot in figure 11 shows that path loss contribute to delay of signal reception and thus, affect the expected/estimated time of arrival of the signal. In indoor geolocation, accuracy and reliability are among the two things to be considered before implementation and deployment of any technology therefore a system whereby as a result of path loss causes delay in the signal reception is not ideal.

This plot in figure 12 shows the statistical probability distribution of received signal strength at different locations. The first detected signal and the point where maximum signal was received are very important in indoor geolocation system. Any other signal received after the maximum point is not considered. This helps the rescue operatives or any search mission you are performing to limit your search within the point where the signal was first received to the point where the maximum signal occurred.

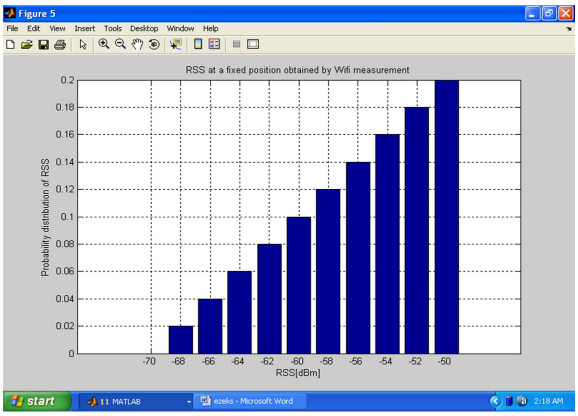

**Figure 12 Plot of RSS at fixed positions**

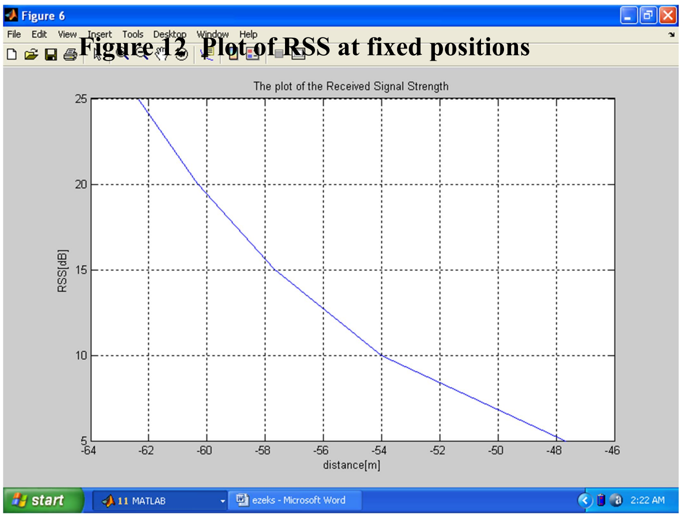


**Figure 13 Received Signal Strength against Distance**

The plot of received signal strength against the distance in figure 13, this is a negative exponential pot that shows that as the distance increases the quality of signal reception will be reduced. That is, as the distance increases the quality of signal reception reduces.

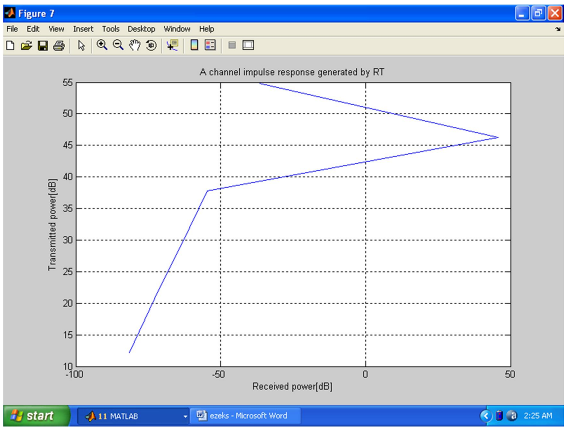


**Figure 14 The plot of Transmitted Power against Received Power.**

This is a plot in figure 14 of transmitted power against the received power. The plot shows that the received power varies with that of power transmitted this may as a result of various propagation loses that the signal has encountered before being recepted at the received end.

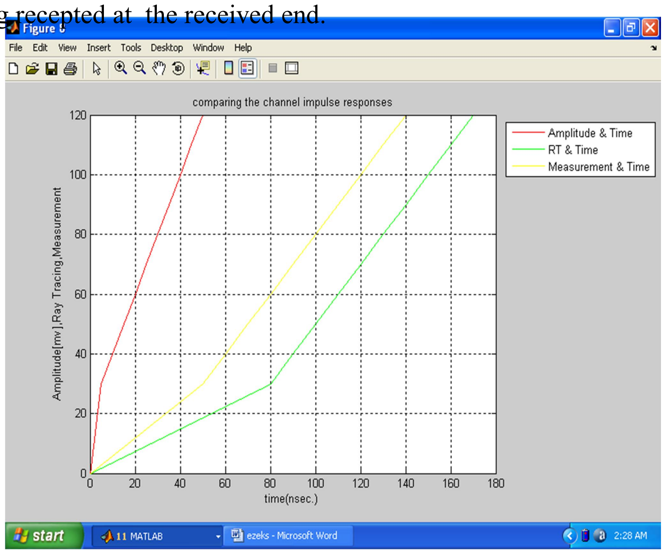


**Figure 15 The plot of Amplitude, Ray Tracing, and WiFi Measurement**

The plot in figure 15 of amplitude, Ray tracing, and Wifi measurement against time. The plot is used to determine an appropriate technique for measuring the accurate time at which the signal arrived. It can be seen that WiFi measurement is a more reliable technique to be adopted.

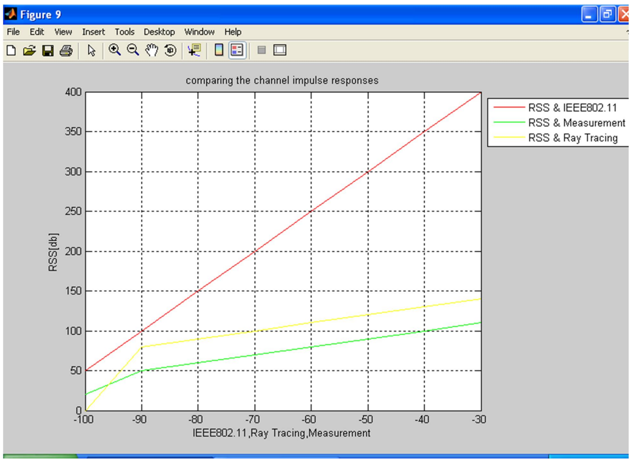


**Figure 16 The plot of IEEE802.11b Standard, RSS and Ray tracing**

The plot in figure 16 the plot of IEEE 802.11b standard, RSS and ray tracing compares IEEE802.11, Ray tracing and wifi measurement against received signal strength. It will be seen that IEEE802.11 standard present a more accurate method for determining the quality of signal received, then followed by the wireless fidelity (wifi) method.

## 5 CONCLUSION

This work was able to come up with the analysis and estimation of the time of arrival and received signal strength for indoor geolocation using MATLAB describes an indoor geolocation localization either by use the received signal strength (RSS) or time of arrival (TOA) of the received signal as their localization metric. Though time of arrival based systems are sensitive to the available bandwidth and also to the occurrence of undetected direct path (UDP) channel conditions which RSS based system are less sensitive to the bandwidth as more resilient to undetected conditions. This paper demonstrate the availability of radio channel modeling techniques to eliminate the costly finger printing process in pattern recognition algorithms by introducing ray tracing (RT) assisted by RSS and TOA based algorithms. The results in figure 8 the effect of pathloss on signal reception, showing free path loss reduces when plotted height of the building which can be used for achieving localization. it was also disovered that pathloss also contributes to signal delay, the plot in figure 12 which is a probability distribution of received signal strength at different location which detect signal at the point where maximum signal was received , this RSS at fixed positions which can be used to determine geolocation. Localization algorithm using more complex algorithms results in a more accurate system. In other words, localization algorithm can be used as a trade-off mechanism between system complexity and localization accuracy.

## REFERENCES

[1] "Location-based services: finding their place in the market" In-stat/MDR,san Jose, CA Tech. Rep, Feb. 2003
[2] Pahlavan, K; Xinrong Li, Makela, J. P., "Indoor geolocation science and technology" IEEE comm. Mag. Volume 40, no.2,pp.112-118,
[3] H. Koshima and J. Hoshen, "Personal locator services emerg," IEEE spectrum, February 2000. pp 41 – 48
[4] G. J. Pottic and W. J Kaiser, "Wireless integrated network sensors," Comm. ACM, May 2000.
[5] Schilit, B., Adams, N., Want, R, " Context-aware computing applications, "IEEE workshop on mobile computing systems and applications. Dec. 1994
[6] Ali H. Sayed, Ahreta Tarighat, and Nima Khajehnouri, "network-Based wireless location," IEEE signal process
[7] P. Jensfelt," Approaches to mobile robot localization in indoor environments" Royal Institute of Tech. (2001)Stockholm, Sweden.
[8] Y. Ko and N.H. Vaudya, " Location-aided routing (LAR) in mobile ad hoc networks" Dallas, TX, 1998
[9] R. Jain, A. Pari and R. Sengupta, "Geographical routing using partial information for wireless ad hoc network" ( 2001)IEEE Pers. Comm.
[10] J.A. Tauber "Location systems for pervasive computing" Area exam Report, Massachusetts Institute of Technology, (2002).
[11] Ravindra S and Jagadeesha S N, (2013), time of arrival based localization in wireless sensor networks: a linear approach, Signal & Image Processing : An International Journal, SIPIJ) Volume.4, No.4,