Enhanced Distance Utilized ToA/RSS to Estimate Position using Trilateration in Outdoor

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Abstract. The subject of target localization is becoming increasingly important with the recent development in science and technology. In this paper, a proposed system included simple equipment on three transmitters. The case study chosen in this work is simulated using Wireless InSite (WI) software to model the campus with its all building. Three Transmitters (TXs) are installed in selected position while twenty Receivers (RXs) are deployed randomly as a target to estimate their position utilizing Time of Arrival (ToA) and Received Signal Strength (RSS) to estimate the distance, the distance error is then obtained and utilized to get the enhanced distance. Trilateration utilizes the enhanced distance to obtain the target location and AoA. The achieved result is addressed using specific equations to estimate the target positions. The accuracy can be assessed by estimating localization error, minimal localization error was found to be 0.2178 while maximum value was 2.8522.

1. Introduction
In the recently developed world, localization ability becomes a very important part of modern life especially with the presence of the internet and smart devices for almost everyone. This development leads to the emergence of Location-Based-Services (LBS) which considered from the most important application involving tracking applications such as (animal, vehicle, and mobile), civil engineer mapping, tracking, and navigation systems... etc. all these applications aiming to the same goal which is target coordinates determination[1].

Reaching for that goal is becoming more complicated since the environment we live in becomes more complicated with too many details, so localization techniques become more affected by the surrounding environment whether indoor or outdoor.

The localization process at outdoor scenario adapting Global Positioning System (GPS) as the main localization technique which can achieve an accuracy of around 5 meters [2]. However, in the case of campus or large office, more accuracy is needed, this is not the case in the indoor environment since signal severely declined inside buildings, in addition to the high cost of GPS receiver [3, 4].

Trilateration is one of the localization technique which is a geometric method for object position determination requiring distance estimation between target and three reference points at least [5]. The distance measured indirectly utilizing Time of Arrival (ToA) or Received Signal Strength (RSS) parameters. Many researchers investigate this subject as in [6] Proposed an improved RSS – trilateration based method for Wireless Fidelity (Wi-Fi) indoor localization where trilateration is implemented for target position determination and then improve the result using a specific reference point, average error found to be 2 meters reduced to 1 meter with the improved scheme. In [7] address the problem of target localization adapting a hybrid RSS and Angle of Arrival (AoA) measurement against of set of very developed recent localization algorithms and the simulation results proved the effectiveness of the proposed algorithm, also it involves a comparison between a hybrid system versus the
classical ones (RSS – only and AoA – only) and there was clear benefit from the measurement integration. In [8] suggested a new localization estimator based on hybrid RSS-AoA measurement in three dimensions (3D) WSNs utilizing the Least – Squares (LS) criterion and resulted in low Root Mean Square Error (RMSE) of the proposed estimator. In [9] analyzed the trilateration technique with a single uncertain reference point. The object location is estimated as an area using two known reference points. The method determines an added value which represents area reduction. This proposed method required costly calculations. In this paper, utilize RSS based distance in real measurement and ToA to estimated distance via Wireless InSite (WI) software, to estimate position localization by trilateration method and measurement AoA estimated.

2. Mathematical Calculations

2.1 RSS Based Distance Measurement

RSS is the strength of a received signal measured at the receiver’s antenna and can be calculated according to Friis equation [10]:

\[ P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} \]  

(1)

Where \( P_t \) is the transmitted power, \( G_t \) and \( G_r \) are the antenna gain of the Transmitter (TX) and Receiver (RX) respectively, \( d \) is the distance between TX and RX, while \( \lambda \) is the carrier wavelength [11].

The propagated signals are subjected to various types of attenuations called Free Space Path Loss (PLo) parameter which can be calculated by [12, 13]:

\[ PLo = 20 \log_{10} (d) + 20 \log_{10} (f) + 20 \log_{10} \left( \frac{4\pi}{\lambda} \right) - G_t - G_r \]  

(2)

To estimate the distance \( (d) \) between the TX and RX coordinator can be based on the equation [14]:

\[ d = 10^{-(RSS-P_t+PLo-\vartheta)/10 \gamma} \]  

(3)

Where \( P_{Lo} \) is the path loss at a reference distance do (1 meter) and it is equal to (19.04 dB) according to equation (2) depending on antenna properties, the path loss exponent \( \gamma \) depends on the environment and which is in a range of 2–6, according to [15]. In this paper, \( \gamma \) is considered as 5. Also, according to [15-17] the standard deviation \( \vartheta \) depended on the environments of case study in the range of 2–14 which assumed to be 12 in this paper. these parameters achieved the most accurate results.

2.2 ToA based Distance Measurement

ToA based distance was estimated using WI software according to the speed of electromagnetic wave propagation, the distance \( d \) is obtained by [18]:

\[ d = c \times t \]  

(4)

Where \( c \) is velocity of light “3×10^8 ms-1”, \( t \) is the propagation time in one way signal with maximum power received with multipath propagation; the time is taken as \( \overline{t} \) value of \( t \) can be calculated as [18]:

\[ \overline{t} = \frac{\sum N_p \tau_{t_k}}{N_p} \]  

(5)
Where \( N_p \) is the number of the paths and \( P_i \) is the time averaged power in watts of the ith path, \( P_R \) is total power receive, \( t_i \) is the ToA for each propagation path which can be calculated from:

\[
t_i = \frac{L_i}{c}
\]  

(6)

Where \( L_i \) is the total geometrical path length [18].

2.3 Trilateration Method

The trilateration method utilizes measured distance between TX and RX which is calculated based on ToA/RSS value for RX coordinates determination. This method needs the presence of three nonlinear reference points that represented by three TXs in this paper. The distance from each TX to RX form a three intersected circles. Distance between each TX and target is equal to the radius \( r \) of the corresponding circle. The point at which all the three circles intersect with each other represents our target which is RX position as shown in figure 1. Target coordinates \((x_t, y_t)\) can be estimated based on equation (7) [1, 19].

\[
\begin{align*}
r_1^2 &= (x_t - x_1)^2 + (y_t - y_1)^2 \\
r_2^2 &= (x_t - x_2)^2 + (y_t - y_2)^2 \\
r_3^2 &= (x_t - x_3)^2 + (y_t - y_3)^2 
\end{align*}
\]  

(7)

\[\text{Figure 1. Trilateration Technique}\]

Where \((x_1, y_1), (x_2, y_2)\) and \((x_3, y_3)\) represent coordinates of TX1, TX2, and TX3 consecutively.

Thus, AoA \( (\theta_i) \) can be determined to utilize target coordinates according to equation (8):

\[
\theta_i = tan^{-1} \frac{y_t - y_i}{x_t - x_i}
\]  

(8)

Where \((x_t, y_t)\) represents reference points (TXs) coordinates [11].

2.4 Distance Error and Enhanced Distance

By comparing RSS based distance estimation and ToA based distance estimation, distance error \( (E_d) \) can be determined.
Where $d_{RSS}$ estimated distance in Rss, $d_{ToA}$ estimated distance in ToA.

The average Distance Error ($E_i$) for each TX was calculated in order to enhance accuracy according to the equation:

$$E_i = |d_{RSS} - d_{ToA}|$$  

(9)

Where $E_i$ is the average Distance Error ($E_i$) for each TX, $d_{RSS}$ is the estimated distance in RSS, and $d_{ToA}$ is the estimated distance in ToA.

$$E_i = \frac{1}{n} \sum_{i=1}^{n} E_{RX}$$

(10)

Where $i = 1, 2, 3...$ is the number of RXs, $n$ number of RXs, $E_{RX}$ summation of RXs error. Each $E_d$ is estimated and their average was calculated. The average $E_i$ the value was subtracted from estimated RSS based distance in order to obtain enhanced distance.

The enhanced distance is adapted to obtain target location and AoA measurement in the real scene.

3. Proposed Model

A simulated case study has been designed using WI software, which represents the campus of the Electrical Engineering Technical College composed of multiple buildings. All of these buildings simulated based on real dimensions with multiple floors and 3.5m height for each one.

Three TXs were deployed in preplanned locations with 2.5m height and highlighted with blue color while twenty RXs scattered randomly over the work area at 1.3m height coded with red color. The location of TXs was determined to cover all the study area based on [19]. The distribution of TXs and RXs are illustrated in figure 2. All properties of both TX and RX are listed in table 1.

Also, the impact of serious effects on wave propagation causes by different building materials (Concrete, Wood, Brick, and Glass,) with a frequency of 2.4GHz band and 1MHz bandwidth [19] . Such impacts were taken into consideration for the entire investigation, where each material thickness, conductivity ($\sigma$), and relative permittivity ($\eta$) were determined based on the recommendation of the International Telecommunication Union (ITU) [20, 21]. The results of $\sigma$ and $\eta$ calculations at a frequency of 2.4 GHz are listed in table 2. Twenty out of fifty RXs were involved in calculations.
Figure 2. Simulation model of the case study (a) 3D view
Simulation model of case study (b) Distribution of TXs and RXs

Table 1. TX and RX antenna properties

| Antenna properties | TX Antenna | RX Antenna |
|--------------------|------------|------------|
| Antenna type       | Directional| Omni-Directional |
| Gain (dBi)         | 19         | 2          |
| Input Power (dBm)  | 30         | -          |
| Polarization       | V          | V          |
| Waveform           | Sinusoid   | Sinusoid   |
| (VSWR)             | 1          | 1          |

Where (VSWR) is the Value for the antenna’s voltage standing wave ratio.

Table 2. Material thickness, conductivity and permittivity values

| Materials | Thickness (m) | σ  | η'  |
|-----------|---------------|----|-----|
| Wood      | 0.030         | 0.012 | 1.99 |
| Brick     | 0.30          | 0.038 | 3.75 |
| Glass     | 0.003         | 0.012 | 6.27 |
| Concrete  | 0.125         | 0.066 | 5.31 |

4. Results and Discussion

4.1 Estimated Distance-Based ToA / RSS
A simulated case study via WI tool utilizes mean ToA for estimating distance depending on equation (4). RSS measured through the Wi-Fi meter application is used for estimating real distance using equation (3). Trilateration method adapting mean ToA based distance used for Rx position determination according to equation (7). All these parameters obtained from TX1 located at (58, 38), TX2 located at (163, 163), and TX3 located at (286, 74) in coordinates system are listed in table 3, 4, and 5 respectively.

The distance error is the difference between estimated distance based ToA (virtual measurement) and distance-based RSS (real measurement), the result of distance error is listed in 5th column in table 3 and 4 and table 5, and it was considered for enhanced distance measurements obtained from all the three TXs. The average distance error for each TX is obtained and subtracted from each RSS based distance to get the enhanced distance. The ToA /RSS based distances and enhanced distance measurement obtained from all the three TXs are represented in figure 3.
Table 3. The enhanced distance with RX position and error obtained from TX1

| RXs | Distance/ToA | RSS | Distance/RSS | Distance Error | Enhanced Distance |
|-----|--------------|-----|--------------|----------------|-------------------|
| RX1 | 53.92088     | -61 | 54.842       | 0.9214         | 52.6423           |
| RX2 | 90.29682     | -72 | 91.016       | 0.7187         | 88.8155           |
| RX3 | 111.06238    | -77 | 114.582      | 3.5194         | 112.3818          |
| RX4 | 122.15514    | -79 | 125.636      | 3.4813         | 123.4364          |
| RX5 | 124.96301    | -79 | 125.636      | 0.6734         | 123.4364          |
| RX6 | 142.21768    | -82 | 144.250      | 2.0322         | 142.0499          |
| RX7 | 127.92662    | -80 | 131.557      | 3.6308         | 129.3575          |
| RX8 | 136.09029    | -81 | 137.758      | 1.6673         | 135.5576          |
| RX9 | 84.66734     | -71 | 86.919       | 2.2518         | 84.7192           |
| RX10| 122.77119    | -79 | 125.636      | 2.8652         | 123.4364          |
| RX11| 117.09386    | -78 | 119.982      | 2.888          | 117.7818          |
| RX12| 85.96945     | -71 | 86.919       | 0.9497         | 84.7192           |
| RX13| 70.65002     | -67 | 72.296       | 1.6462         | 70.0962           |
| RX14| 100.1225     | -74 | 99.797       | 0.2157         | 97.5965           |
| RX15| 83.4929      | -71 | 86.919       | 3.4263         | 84.7192           |
| RX16| 97.66844     | -74 | 99.797       | 2.1281         | 97.5965           |
| RX17| 100.03051    | -75 | 104.500      | 4.4693         | 102.2998          |
| RX18| 135.06541    | -81 | 137.758      | 2.6922         | 135.5576          |
| RX19| 45.56361     | -58 | 47.766       | 2.202          | 45.5636           |
| RX20| 100.11492    | -74 | 99.797       | 0.31           | 97.5965           |

Table 4. The enhanced distance with RX position and error obtained from TX2

| RXs | Distance/ToA | RSS | Distance/RSS | Distance Error | Enhanced Distance |
|-----|--------------|-----|--------------|----------------|-------------------|
| RX1 | 110.1573     | -77 | 114.5817638 | 4.4244         | 112.5018          |
| RX2 | 106.4476     | -76 | 109.424735  | 2.9772         | 107.3447          |
| RX3 | 81.74002     | -70 | 83.0071501  | 1.2671         | 80.92715          |
| RX4 | 47.67736     | -59 | 50.01675401 | 2.3394         | 47.93675          |
| RX5 | 69.53046     | -67 | 72.29620544 | 2.7657         | 70.21621          |
| RX6 | 31.65794     | -50 | 33.04574166 | 1.3878         | 30.96574          |
| RX7 | 34.7677      | -52 | 36.23393521 | 1.4662         | 34.1594           |
| RX8 | 45.18409     | -58 | 47.76562925 | 2.5815         | 45.68563          |
| RX9 | 77.99229     | -69 | 79.27121293 | 1.2789         | 77.19121          |
| RX10| 40.84727     | -56 | 43.56277163 | 2.7155         | 41.48277          |
| RX11| 91.714       | -73 | 95.30496    | 3.591          | 93.22496          |
| RX12| 78.91759     | -69 | 79.27121293 | 0.3536         | 77.19121          |
| RX13| 97.48213     | -74 | 99.79654438 | 2.3144         | 97.71654          |
| RX14| 64.11269     | -65 | 65.93492301 | 1.8222         | 63.85492          |
| RX15| 82.83985     | -70 | 83.0071501  | 0.1673         | 80.92715          |
| RX16| 73.53422     | -68 | 75.70342063 | 2.1692         | 73.62342          |
| RX17| 63.15675     | -64 | 62.96736263 | 0.1894         | 60.88736          |
| RX18| 60.2214      | -63 | 60.13336448 | 0.088          | 58.05336          |
| RX19| 117.5697     | -78 | 119.981836  | 2.4121         | 117.9018          |
| RX20| 66.28248     | -66 | 69.0423402  | 2.7599         | 66.96234          |
Table 5. The enhanced distance with RX position and error obtained from TX3

| RXs | Distance/ToA | RSS  | Distance/RSS | Distance Error | Enhanced Distance |
|-----|--------------|------|--------------|----------------|-------------------|
| RX1 | 185.3954     | -88  | 190.1584     | 4.763          | 187.5584          |
| RX2 | 140.0944     | -82  | 144.2499     | 4.156          | 141.8499          |
| RX3 | 125.197      | -79  | 125.6364     | 0.439          | 123.2364          |
| RX4 | 181.3463     | -87  | 181.5999     | 0.254          | 179.1999          |
| RX5 | 117.1647     | -78  | 119.9818     | 2.817          | 117.5818          |
| RX6 | 133.0669     | -81  | 137.7576     | 4.691          | 135.3576          |
| RX7 | 155.5861     | -84  | 158.1669     | 2.581          | 155.7669          |
| RX8 | 125.2937     | -79  | 125.6364     | 0.343          | 123.2364          |
| RX9 | 173.0658     | -87  | 173.4265     | 0.361          | 171.0265          |
| RX10| 115.1149     | -78  | 119.9818     | 4.867          | 117.5818          |
| RX11| 187.4647     | -88  | 190.1584     | 2.694          | 187.7584          |
| RX12| 158.7159     | -84  | 158.1669     | 0.549          | 155.7669          |
| RX13| 167.8795     | -86  | 173.4265     | 5.547          | 171.0265          |
| RX14| 162.2423     | -85  | 165.621      | 3.379          | 163.221           |
| RX15| 147.9684     | -83  | 151.0482     | 3.08           | 148.6482          |
| RX16| 113.6788     | -86  | 114.5818     | 0.903          | 112.1818          |
| RX17| 203.1067     | -90  | 208.5045     | 5.398          | 206.1045          |
| RX18| 167.4593     | -85  | 165.621      | 1.838          | 163.221           |
| RX19| 158.7159     | -84  | 158.1669     | 0.549          | 155.7669          |
| RX20| 125.197      | -79  | 125.6364     | 0.343          | 123.2364          |

Utilizing enhanced distance, the target position was determined via trilateration, localization error was estimated by comparing estimated and actual target coordinates as shown in table 6. By obtaining the target location by trilateration, AoA can be estimated according to equation (8).

Table 6. Target location from trilateration method with localization error and AoA measurements

| X-Axis trilateration in RSS | Y-Axis trilateration in RSS | x- Actual | y- Actual | Localization Error X-axis | Localization Error Y-axis | AoA Related in to TX1 |
|-----------------------------|-----------------------------|-----------|-----------|--------------------------|--------------------------|-----------------------|
| 98.5665                     | 70.9824                     | 100       | 71.5      | 1.4335                   | 0.5176                   | 58.286                |
| 145.0206                    | 56.9639                     | 147       | 57.5      | 1.9794                   | 0.5361                   | 35.91                 |
| 162.4096                    | 81.2178                     | 161       | 81        | 1.4906                   | 0.2178                   | 85.15                 |
| 121.214                     | 143.2546                    | 119       | 144       | 2.214                    | 0.7454                   | 78.37                 |
| 169.3665                    | 92.2771                     | 170       | 93        | 0.6335                   | 0.7229                   | 270.20                |
| 164.0026                    | 132.435                     | 166       | 131       | 1.9974                   | 1.435                    | 297.10                |
| 142.9302                    | 135.5262                    | 142.5     | 134.5     | 0.4302                   | 1.0262                   | 276.85                |
| 169.5046                    | 116.0909                    | 168       | 118       | 1.5046                   | 1.9091                   | 88.97                 |
| 116.609                     | 100.2438                    | 115       | 101       | 1.609                    | 0.7562                   | 282.67                |
| 134.6275                    | 134.2958                    | 132       | 137       | 2.6275                   | 2.7042                   | 279.604               |
| 169.6494                    | 71.5412                     | 171       | 71.5      | 1.3506                   | 0.0412                   | 318.92                |
| 101.4312                    | 112.9933                    | 102.5     | 113       | 1.0688                   | 0.0067                   | 73.05                 |
| 115.1478                    | 78.0556                     | 118       | 76        | 2.8522                   | 2.0556                   | 58.701                |
| 132.0737                    | 104.1686                    | 130       | 107       | 2.0737                   | 2.8314                   | 273.39                |
| 123.6355                    | 91.9788                     | 124.5     | 89.5      | 0.8645                   | 2.4788                   | 45.44                 |
| 138.5306                    | 93.373                      | 139.5     | 93.5      | 0.9694                   | 0.127                    | 314.98                |
| 127.4849                    | 113.2646                    | 128       | 111       | 0.5151                   | 2.2646                   | 284.05                |
### Table

|          | A1  | A2  | A3  | A4  | A5  | A6  | A7  | A8  | A9  | A10 | A11 | A12 | A13 | A14 | A15 | A16 | A17 | A18 | A19 | A20 |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Location | 0   | 20  | 40  | 60  | 80  | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 | 380 |
| Distance | 0   | 20  | 40  | 60  | 80  | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 | 380 |

### Diagram

(a) Distance/ToF
(b) Distance/RSS
(c) Enhanced Distance
4.2 AoA Measurement
After obtaining enhanced distance and application of the trilateration method to obtain target position, AoA can be estimated according to equation (8).

5. Conclusion
In this paper, a case study of selected work area is simulated using WI packages in order to estimate the locations of many targets. For such experiment, 20 RX represent such targets are deployed randomly in the case study area. The distance between the TX and target are estimated in two methods ToA and RSS, the difference between the two represents distance error which is utilized to estimate enhanced distance. the results showed that more accurate results can be obtained with less TX-RX distance and if there is no barrier between TX and the target. The accuracy can be assessed by estimating localization error, minimal localization error was found to be 0.2178 while maximum value was 2.8522.

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