Indoor Localization Based on Time of Arrival Using Multi-Zone Technique

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Abstract. Indoor position localization suffers from the regressive signal when the system implement based on Receive Signal Strength (RSS) and time synchronization when implement based on Time of Arrival (ToA). Those problems lead to high error in terms of position localization. To mitigate those errors many techniques and methods are deployed such as NLOS identification, Maximum Likelihood (ML), and weighted least-squares (WLS). In this paper, a new technique based on optimization of transmitter location has been proposed by separating the case study building into multi-zone, each zone having specific parameters which defer from other ones. The deployed receivers were 8 for the zones (*A-F*) and 20 into the zone *G* to be 68 for the whole system. There are three transmitters deployed with a changeable position to select a better one. The results confirm that the error improved from (0.638m) based on individual TOA to (0.136m) by using propose Multi-zone ToA, while improved from (0.756m) rely on individual RSS to (0.1223m) based on Multi-Zone RSS.

Keywords: ToA, RSS, indoor localization, multi-zone.

1 Introduction

Indoor localization gains attention and popular topic for researchers recently to locate the person and any other object. The indoor localization constructed to correspond with the crowded building to track the children, patient movements, monitoring, and security. The common technique widely used to find location is the Global Position System (GPS). However, GPS is convenient in outdoor environments and there are constraints and limitations that obscured GPS service like the position between high building or inside building that disconnect satellite with targets [1]. In this situation, indoor localization systems are used to estimate the position in any area that GPS doesn't work so well in it. For each environment, several methods are used such as, Time of Arrival (ToA) [2], [3], [4], Time Deference of Arrival (TDoA) [5], Angle of Arrival (AoA) [6], and Receive signal strength (RSS) [7], [8], [9], [10], [11]. Also, there are hybrid methods such as, ToA/AoA [12], RSS/ToA [13], [14], and TDoA/RSS [15]. In general, signal characteristics use to construct the indoor localization systems in most projects to estimate the distance between reference points (RPs) and targets. In addition, Wireless Fidelity (Wi-Fi) is proliferate everywhere, subsequently, a lot of indoor localization systems design based on Wi-Fi [16], [17], [18], [19]. However, indoor wireless communications suffer from several

constraints and challenges that impact system reliability. The phenomenon widely recognized effect on system accuracy called multipath which happens in Non-Line of Sight (NLoS) environments when obstacles separate transmitters and receivers [1]. Furthermore, time synchronization and time measurement are common problems in inferring location using ToA [20]. To address those problems, many researchers proposed several techniques and algorithms like [21], [22], whose proposed NLOS identification technique to alleviate the impact of multipath. Also, Maximum Likelihood (ML) and weighted least-squares (WLS) have been formulating for indoor localization [23], [24]. To improve position systems based on RSS, Wi-Fi fingerprint also has already been proposed in [25], [26]. In this paper, the Multi-Zone technique will propose to mitigate the NLOS phenomenon and complexity into a crowded building. Such a propose technique aims to separate the case study building into seven zones each one having a specific parameter such as path loss exponent and noise value. In addition, to mitigate the regressive signals and find suitable coverage to whole targets, optimum position (OP) will determine to deploy the transmitters. Both procedures aim to carry out an optimum indoor localization system with high accuracy.

2 Localization based ToA & RSS

The estimated distance between RPs and targets can be estimated depending on spent time needs to reach receivers, where RPs could be access points or anchor points while the targets is the receives points. The exact distance can be calculated as [2]:

$$d_i = ||x - x_i|| = \sqrt{(x - x_i)^2 + (y - y_i)^2} \qquad i = 1.2. \dots . k \qquad (1)$$

The distance between RPs and targets can be calculated depending on TOA as following [27]:

$$d_i = C * (time_{arrival} - time_{sent}) \qquad (2)$$

Where C, is the speed of light $\approx 3 * 10^8$(m/s). As mentioned above, there are constraints due to multipath environments. Therefore, (1) can be written as following [2]:

$$d_i = ||x - x_i|| + \beta_i + m_i \qquad (3)$$

Where $\beta_i(m)$ equal to 0 in LOS and greater than 0 in NLoS, m_i is noise value.

To estimate targets position, reference path loss calculates in one meter which recommended in [20]. In addition, the path loss for the distance between transmitters and receivers can express as [2, 20]:

$$PL(d) = Plo - b_i - 10\gamma log 10 \frac{||x - x_i||}{d_o} \qquad (4)$$

Where *Plo* IS reference path loss, b_i is positive bias, γ is path loss exponent, z is the log-normal shadowing and can express as a zero-mean Gaussian random variable, i.e. $n_i \sim N(0.\sigma_{ni}^2)$ *and* $m_i \sim N(0.\sigma_{mi}^2)$ is the level of noise (m).

When measurements of ToA and RSS presented, then can do some manipulation by list the both RSS and TOA as one vector, $p = [p_i]^T$ and $d = [d_i]^T$, $(p.d \in \mathbb{R}^N)$. Then joint likelihood function can write as following [23]:

$$\Lambda(p.d|x.b_i.\beta_i) = p(p|x.b_i)\,p(d|x.\beta_i) = \frac{1}{\sqrt{2\pi\sigma_{ni}^2\,\sigma_{mi}^2}}$$

$$\exp\left\{ -\frac{(pi-po+bi+10\gamma log_{10}\frac{||x-xi||}{d0})^2\;\sigma_{mi+(di||x-xi||-\beta i)^2\sigma_{ni}^2}^2}{\sigma_{ni}^2\sigma_{mi}^2} \right\} \qquad (5)$$

Also, the hybrid *ML* for $(x.b_i.\beta_i)$. can be written as following [28]:

$$\{x.bi.\beta i\} = argmin \sum_{i=1}^{N} x.bi.\beta i \qquad (6)$$

However, according to [23], the equation above does not close from exact results also it's difficult to distinguish between LOS and NLoS. Accordingly, hybrid ML is not a perfect solution for multipath impact. The authors in [23] suggested an integrated ToA and RSS to employ the advantage for both techniques which can mitigate the corresponding drawback for each one, such estimate distance calculates depending on RSS and ToA as following:

$$(d_i)^{RSS} = 10^{\frac{po-pi-\frac{b^{\wedge}max}{2}}{10\gamma}} \qquad (7)$$

$$(d_i)^{TOA} = d_i - \frac{\beta^{max}}{2} \qquad (8)$$

The normalized of (7) and (8) can be calculate as following [23]:

$$\in = \frac{|d_i^{RSS}-d_i^{ToA}|}{\max\{d_i^{RSS}.d_i^{ToA}\}} \qquad (9)$$

To estimate targets located, trilateration method could be applied as shown in figure (1) which depending on distances between RPs and targets [1], [20]:
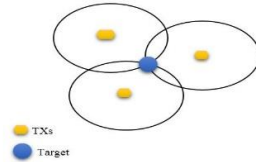

Fig.1. Estimate position using trilateration methods

3 Case study

In this paper, the Wireless Insite Package is applied to design the selected case study building. The campus of electrical engineering technical college is the experimental case study. Such a building consists of three floors; our experiment is applied on the first floor only. Such a floor is separated into 7 zones (A-G) related to the content of each zone such as, walls, objects, and types of materials that impact propagation patterns to give specific parameters for each zone. The receiving point is distributed as 68 receivers 8 for each zone except zone G with 20 receivers. The number of transmitters is three with a changeable position to select a better one.
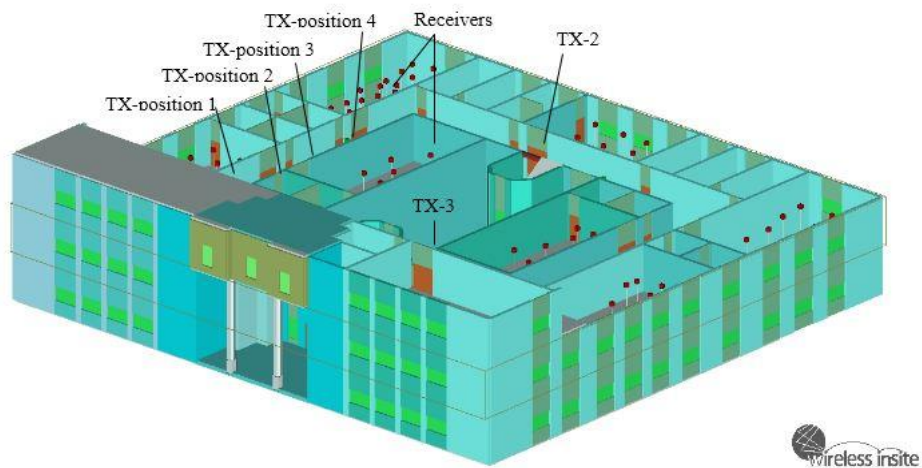

Fig. 2. Transmitters position that selected

In this research, 4.5GHZ frequency was selected in addition to an omnidirectional antenna for transmitters and receivers have been used as shown in Table (1).

Table 1: The characteristics of antennas

Antenna properties	TX Antenna	RX Antenna
Antenna type	Omni-Directional	Omni-Directional
Input Power (dBm)	15	-
Gain (dBi)	7	1
E-Plane HPBW	10°	90°
Waveform	Sinusoid	Sinusoid
Temperature (k)	293	293
Polarization	V	V
Received Threshold (dBm)	-130	-130

4 Results & Discussion

The performance of indoor localization using ToA with the proposed technique, illustrated in figure (3a). In OTP with a multi-zone technique, the position of transmitter played the main role to improve the performance of systems by decrease distance error. To find OTP, the position of the transmitter has been changed 4 times. The average distance error in the fourth position is (0.136m). However, the first position was the worst one with average distance error (0.638m).

In addition, position estimation based on RSS method has been improved by using the proposed technique. As mention, the regressive RSS is the main challenge. By using OTP, the long-distance can be alleviated, subsequently, the performance of the system will be improved. Figure (3b) illustrates the distance error in each transmitter's position. The fourth position is better than others with average distance error (0.1223m) even better than ToA. In contrast, the first position was the worst one with average distance error (0.756m) and that illustrates the impact of the long-distance on RSS measurements to implement indoor localization.
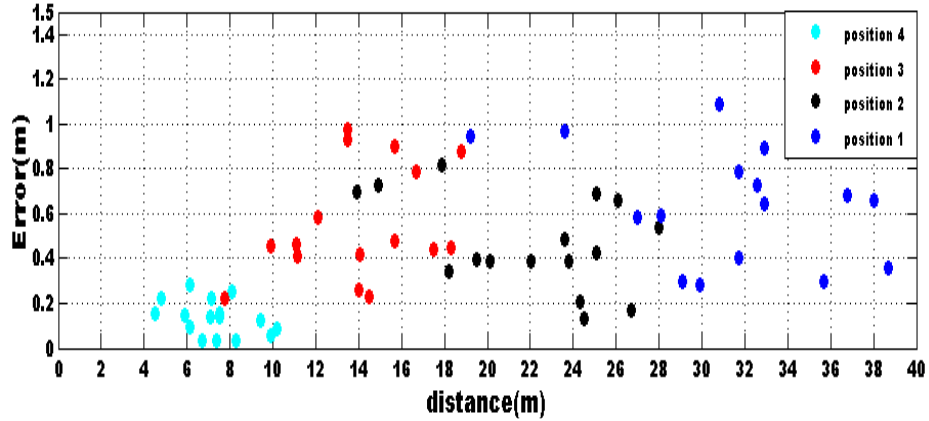
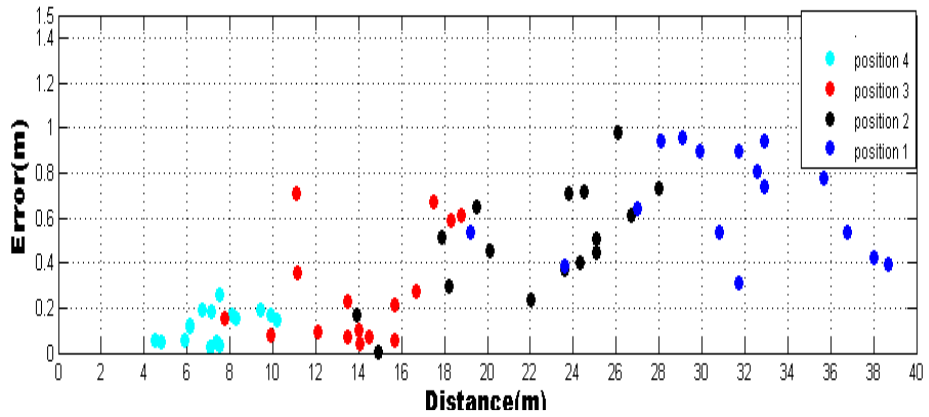**Fig.3a**. Distance error in difference TX position using TOA method

Fig.3b. Distance error in difference TX position using RSS method

5   Conclusions

In this research, a proposed OTP technique is applied with each RSS and ToA in order to find locations of 68 targets deployed in a preplanned manner in a selected building. Such a building has been simulated using the Wireless Insite package to apply the proposed techniques in order to show the performance of position locations. Three transmitters based on 4.5 GHz are deployed in a selected place within a case study building. The results confirm that the error decreases significantly (which calculated as the differences between exact and estimated position) based on the proposed OTP combined with RSS and ToA. Also, the results show that such error has been enhanced from (0.638m) to (0.136m) using the proposed OTP. In contrast, the OTP with RSS evolves the errors from (0.756m) to (0.1223m) which confirms that OTP with RSS is slightly outperformed OTP with ToA.

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