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A Comprehensive Comparison for Different Hybrid Based Localization Algorithms for Indoor Communications

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HIGHLIGHTS

- Best way to increase the accuracy of locating places inside large buildings.
- Hybrid algorithms are used to deploy the advantages of one algorithm to overcome the drawbacks of the other.
- A hybrid algorithm based on AoA/RSS, with Omni and directional antennas, is used to estimate the locations.

ARTICLE INFO

ABSTRACT

The era of the wireless communication-based indoor environment has resulted in several challenges represented by signal reflection, diffraction, and attenuation. Thereby, it affects several wireless-based applications such as positioning, localization, monitoring different objects. With such challenges, estimation error would be increased significantly, and the accuracy will be reduced. To handle such challenges, several new approaches were proposed by many researchers. The most interesting approach for the localization purpose was the hybrid localization approach. A combination of several parameters would be utilized to propose methods that take advantage of these parameters. In this work, a comprehensive analysis was carried out for results obtained based on the proposition of two hybrid algorithms for localization in an indoor environment. The first algorithm utilized the Received Signal Strength (RSS) and Angle of Arrival (AoA) parameter to be tested for both Omni and Directional antenna type Access point (AP) device. While the second algorithm was based on the use of Time of Arrival (ToA) and RSS, which have been calculated via Wireless InSite (WI) software. The analyzing results indicate that using AoA/RSS method with the Omni AP antenna has achieved higher accuracy for the overall normal distribution scenario. However, ToA/RSS has shown higher accuracy estimation for far point distribution. Meanwhile, AoA/RSS with Directional antenna AP has an accuracy limited with distribution location. Due to the characteristics of the directional antenna pattern.

1. Introduction

The innovation-based indoor localization has faced a wide rise in our regular daily existence, especially with cell phones and the Internet of Things (IoT). One of the most interesting technologies was the position-based systems where the position assessment could be considered the most fascinating manner for IoT-based applications [1]. Such innovation could be used in the airport terminals, voyaging stations, markets to deal with the motivation behind following and finding the position of somebody [2]. The Global Position System (GPS) has been utilized widely and effectively for localization and positioning estimation for an outdoor environment. Notwithstanding, performing it for indoor scenarios has brought about a wide scope of difficulties and disadvantages [3]. The most important difficulties were due to the small area of such environment and the effect of different obstacles, objects, and walls, which will affect the signal availability and efficiency of the utilized system in performing positioning and localization issues [4]. Hence, a localization-based indoor environment has been difficult to perform due to several reasons related to the intricacy of such an environment, the impacts of reflection, diffraction, and the serious effects of different walls located inside the indoor environment [5,6]. As a result, the researchers proposed new concepts and involved them with different indoor localization issues, the Wireless Fidelity (WiFi) [7-9].

Wide scope of strategies and methods were adopted by researchers for localization. For instance, methods based on the Time-of-Arrival (TOA) were proposed by several researchers as in [10-11]. With accurate results achieved by their works. However, using such a method requires the availability of synchronization between the target point and the reference points. Meanwhile, another method was based on the use of the Angle-of-Arrival (AoA) method, which has been utilized in many

academic researchers as in [12]. However, lower accuracy results were achieved by this method due to the complexity of the indoor environment and its effects on wireless signal propagation. In addition, it brought several drawbacks as it requires extra cost and time. On the other hand, Time Difference of Arrival (TDOA) was another important method to be followed by many researchers as in [13]. The basic concept of such a method depends on the received signal time at two reference points and the speed of the signal traveling between the target and the reference points. Then, the difference in arrival time would lead to obtaining the difference in distance. Meanwhile, groups of researchers presented a method based on the use of the Received Signal Strength (RSS) as in [14-18]. Such a method has got interested by researchers recently due to its lower implementation costs. However, a relatively lower accurate result has been reported using this method in indoor localization. These proposed methods considered two types of points, the first with known coordination denoted as (AP) and the second with unknown coordination denoted as (Rx).

Several localization-based systems methods have been constructed by researchers and industries. This section will focus on TOA and RSS methods as a related method for our proposed algorithm. For example, in Chen et al., [8] work, a system for localization and positioning within an indoor environment based on WiFi technologies has been proposed. The utilization of such technology was based on its higher reliability and availability with smartphones and other devices. The proposed system has been implemented with two scenarios. The first was the offline stage, where the data was obtained and gathered in the database. The values stored in this database would represent the reference value. While the second stage was the real-time measurements for moving targets. The results obtained showed high effectiveness on measurements, leading to a highly accurate system. In addition, in Yuvaraj and Gowd's work [17], another system was implemented by utilizing WiFi technology. It has been used path loss to obtain the desired distance between the AP and Rx points. Such distance represents the separation between the known points denoted as reference points and the targets. They utilized the trilateration method to estimate the final estimation coordination based on the distance which has been measured. Furthermore, in [7], a localization system for an indoor environment has been proposed using deep learning. Particularly, in localization, there are two phases, online and offline. The fingerprint database is built from the RSS measurement for the first phase. While for the second phase, an algorithm would match the real measurements with a database to adopt those measurements. The difference in measurements would show a significant decrement in estimation error.

Another interesting work was performed in [9] by proposing a methodology for WiFi-based localization. Three AP were deployed in the interested area to estimate the target's location and use the trilateration method. Results obtained encouraged estimation. In recent years, researchers have started working on a hybrid approach for localization. Such as the RSS/TOA-based method as in [19] and based on the use of likelihood function to perform localization in Wireless Sensor Network (WSN). However, such localization-based methods did not consider the effects of different building materials, structures, and objects that may face any typical indoor environment. In addition to that, a hybrid method based on TDOA/RSS has been proposed as in [20] and based on the use of the Bisection procedure for location estimation. This paper presents a comprehensive analysis and comparison between three different hybrid-based localization algorithms for indoor localization issues. These three algorithms were proposed in previous works and applied for the same case study modeled in Wireless InSite software [21].

The paper should be organized into logical parts or sections. Any subsection is given a brief numbered heading. The contents include the introduction that should clearly define the nature of the problem, and the references should be made to previously published papers. Theoretical, experimental results, discussions, and conclusions form the main sections of the paper. The theoretical section extends the analytical background of the article and develops a new formulation of the problem. Calculations are achieved here using the developed equations, and the modifications should be pointed out. Depending on the suggested research methods, the experimental investigation is achieved, using the testing instruments or designing and manufacturing a test rig. Materials and methods are detailed here. In the results and discussions section, the significance of the obtained results should be pointed out. The citations and the discussions of the kinds of literature should be avoided in this section. Sometimes results and discussions are combined in one section.

2. The Proposed Localization Algorithms

In this paper, a comparison between three proposed hybrid localization algorithms for indoor localization will be carried out. Such comparison would consider the parameters utilized (ToA, AoA, and RSS). The accurate location estimation results obtained from all these parameters would be considered the basis for our comparison. The three proposed algorithms will be summarized below.

2.1 Hybrid based AoA/RSS method (Omni)

The first algorithm considers the AoA/RSS method for localization and coordination estimation. AoA is measured and presented in degree, and it has an absolute value when the orientation is zero or pointing to the north. Otherwise, it would have a relative value [22]. Meanwhile, RSS represents the indication for signal strength which measured the power value transmitted from an AP and received by the receiver or reference point (Rx) [23]. It is worth mentioning that RSS represents the summation of the received power, total noise, and interferences, as expressed in equation (1). It should be mentioned that in this work it has been proposed an Omni-directional antenna type for AP and Rx points to be involved with location estimation.

$$RSS = P_R + I_{Total} + N_{Total} \qquad (1)$$

Where P_R represent the received power, value obtained from the received point, I_{Total} represent the value of the total interferences and N_{Total} represent the total noise in the system. For our scenario, WI software will consider the value of P_R and calculate based on below equation (2) [21].

$$P_R = \sum_{i=1}^{NP} \frac{\lambda^2 \beta}{8\pi\eta_0} |E_\theta, ig_\theta(\theta i, \Phi i) + E_\Phi, ig_\Phi(\theta i, \Phi i)|^2 \tag{2}$$

Where λ is the wavelength, β is the overlapping of the frequency spectrum, η_0 is the impedance of the free space, E_θ, i and E_Φ, i are the theta and phi components of the electric field of the ith path at the receiver point, NP is the total number of paths, and finally $\theta i, \Phi i$ gives the direction of arrival.

The steps for this algorithm are represented as follows:

Step1: prepare the database and collect the data from WI software based on both RSS and AoA parameters.

Step2: The next step is to enter the AP coordination of XTx and YTx, which is supposed to be known for our localization algorithm. Then the algorithm would obtain the optimum path based on the values of RSS of each received point and from each AP device. Based on the previous step, several parameters of optimum path would be selected, such as distance, theta (θ), and phi (Φ).

Step3: The algorithm would calculate the angle between the AP and the received point $\beta_{AP,Rx}$ based on equation (3).

$$\beta_{AP,Rx} = \alpha + \pi. \tag{3}$$

Where α is the direction of arrival in phi (Φ) calculated using WI software and for each received point.

Step4: The final step includes calculating the x and y coordination values for the received point or target within the indoor environment based on equations (4) and (5), respectively.

$$XR_x = XT_x + d * \cos(\beta) \tag{4}$$

$$YR_x = YT_x + d * \sin(\beta) \tag{5}$$

Where (XR_x and YR_x) represent the coordination of the targeted received point, representing the output of our presented algorithm.

2.2 Hybrid based AoA/RSS method (Directional)

The second algorithm also considered a hybrid AoA/RSS method for localization. However, the presence of 2 static and directional AP devices has been considered to perform localization on each floor. Each AP device would calculate the RSS and AoA values for each received point to be localized. This algorithm proposed the same previous step of the first algorithm. However, the utilization of a directional antenna with specific properties would be investigated in this work in indoor localization estimation. The methodology of our proposed hybrid algorithm could be clarified, as seen in Figure 1.

2.3 Hybrid based ToA/RSS method

The third algorithm considered a hybrid method of RSS and ToA, where the data collected from WI software would represent the RSS value obtained from every path located between the AP and each Rx point, the value of ToA in (ns). The parameters of the optimum path would be stored in the database to be handled within our proposed algorithm.

Our algorithm has been designed in MATLAB program, the procedure of it would be summarized into the below steps:

Step 1: the first step is to enter the number of AP and Rx points and enter the total area size. A total of 400 iterations were selected for our algorithm procedure along with the Gaussian Newton Algorithm (GNA), which has been considered the basis of our proposed localization algorithm.

Step 2: Then, in the next step, the estimated distance (Distance estimated) per each Rx point would be calculated based on equations (6) and (7).

$$Distance\ estimated = \sqrt{(\mathrm{x}i - \mathrm{x}k)^2 + (\mathrm{y}i - \mathrm{y}k)^2} \tag{6}$$

$$\mathrm{t}i = \frac{Distance\ estimated}{\mathrm{c}} \tag{7}$$

Step 3: Furthermore, the distance derivatives (Deriv. Distance) would be calculated using equation (8) and for both x and y coordination.

$$Deriv.\ Distance = \frac{\mathrm{x}1(\mathrm{i}) - \mathrm{x}(\mathrm{k})\ /\ Distance\ estimated}{\mathrm{y}1(\mathrm{i}) - \mathrm{y}(\mathrm{k})\ /\ Distance\ estimated} \tag{8}$$

Where i represents the number of Rx points, and k represents the number of AP devices.

Step 4: The Δ (Delta) would be calculated in the next step as clarified in equation (9). The Distance Noise has been obtained based on the value of distance measurement error ratio, which has been selected previously to be equal to (0.05).

$$\Delta = (-(\text{Deriv. Distance Trans}(\text{Deriv. Distance}))^{-1 \times \text{Transpose}(\text{Deriv.Distance})} \times \big(\text{Deriv.Distance} - \text{Distance Noise}(x1(i),y1(i))\big) \quad (9)$$

Step 5: The Rx coordination of x and y would be obtained in the final step and based on equations (10) and (11), respectively. Finally, after completing the total number of Rx points and the selected iteration.

$$Estimated\ Rx\ Coordination, x1(i) = Distance\ _{estimated} \times Transpose\ (\Delta) \quad (10)$$

$$Estimated\ Rx\ Coordination, y1(i) = Distance\ _{estimated} \times Transpose\ (\Delta) \quad (11)$$

Step 6: A final figure would be withdrawn to clarify the actual Rx coordination and the estimated coordination from the previous step.

3. Case Study

The case study selected for our proposed algorithm is the 2nd and 3rd floor in the building of electrical department of University of Technology. It was designed and simulated using the WI software, as clarified in Figure 2 [24]. In addition, it has been distributed a total of three AP devices with 2.5 m height at each of the selected floors to perform the localization as a reference point. Meanwhile, it has been distributing a total of 11 and 10 target points (Rx) to be localized within the 2nd and 3rd floor, respectively. The distribution placement for both AP's and Rx points can be seen in Figure 3. The parameter selected for antennas of both AP and Rx has been listed in Table 1. In this work, it has been considered the effect of building materials, structure, and the frequency sensitivity material on the accuracy of localization and wave propagation to achieve a reliable algorithm to be considered the 3-Dimension (3D) investigation. Such consideration would be based on obtaining the value for Relative Permittivity (ε) and Conductivity (σ) for each utilized material in our case study and as listed in Table 2. This consideration was to meet the requirements of the International Telecommunication Union (ITU) [25].
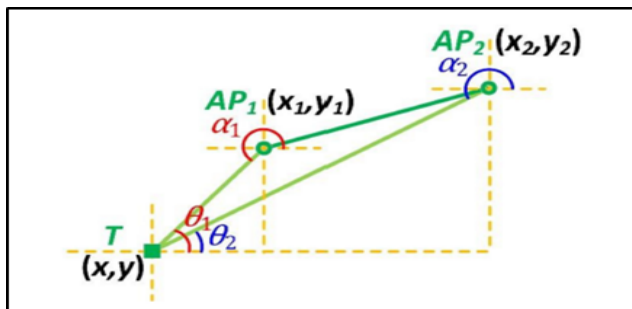

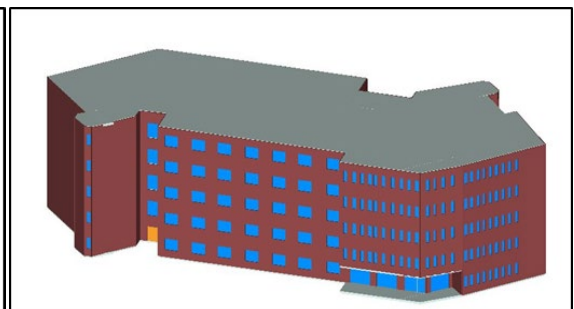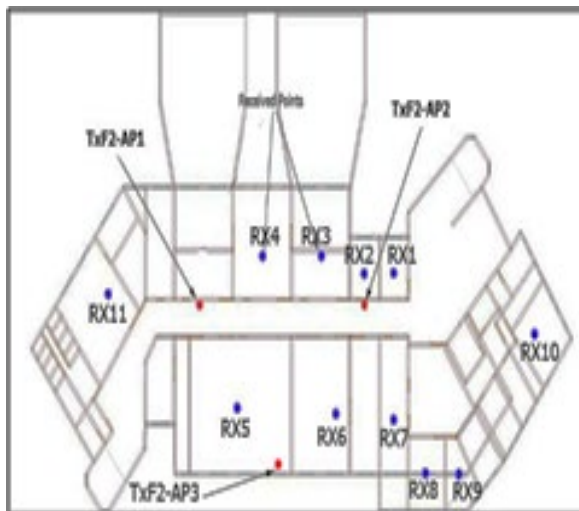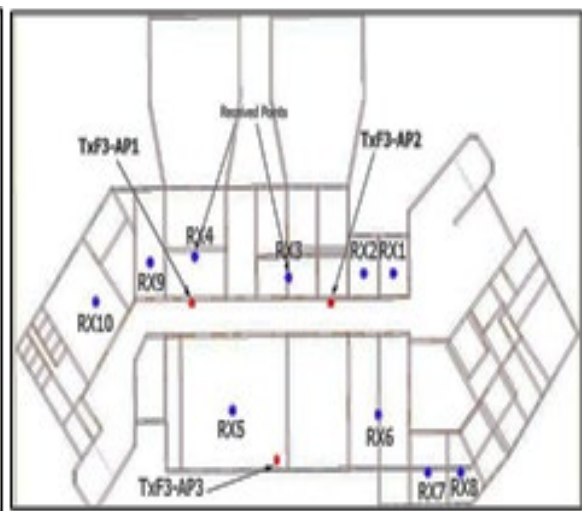**Figure 1:** Methodology of AoA based localization by using two known AP devices

Figure 2: The simulated case study building

Figure 3: The distribution of AP's and received points per (a) 2nd floor and Figure 3 Continued (b) 3rd floor

4. Results and Discussion

The performance of our proposed algorithms has been evaluated based on the values of optimum RSS, ToA, AoA, and the separation distance located between each AP to each Rx point obtained from the software of WI. The (x, y) coordination results for the tested Rx point obtained from the three methods have been listed in Tables 3 and 4 for floors 2 and 3, respectively. The result of our proposed hybrid localization algorithms for each Rx point as compared with the actual coordination has shown an accurate estimation, as seen in figure 4, and for 2nd and 3rd floor, respectively. It can be noticed that ToA/RSS algorithm has shown higher efficiency in coordination estimation. While AoA/RSS using Directional AP antenna has failed to localize some Rx points that located far away from the angle of antenna radiation

A ranging-based error has been performed between both coordination to indicate each proposed algorithm's higher accuracy and effectiveness. A ranging error has been considered for both the x and y axes for the two investigated floors, as seen in figures 5 and 6. Generally, it can be noticed that AoA/RSS method with a directional antenna has failed to localize the Rx point between (7-11) due to reasons related to being far away from the antenna radiation pattern. While for the points within the angle of the radiation pattern, it achieved a relatively lower error range for estimation coordination. Better analysis for this criteria can be illustrated in Figure 7. In addition, ranging error values obtained from the three methods have been listed in Tables 5 and 6.

Furthermore, the Min. and Max. Ranging error obtained from all proposed method has been listed in Table 7. It can be concluded that the straightforward Rx points have achieved better results in the case of using the directional antenna. However, by moving for far points facing different objects and obstacles, the AoA/RSS has shown a weakness in localizing these points. Meanwhile, ToA/RSS has shown a higher stability degree in localization manner for all RX points. As a result, it can be concluded that using ToA/RSS and AoA/RSS (Omni) for 2nd and 3^{3d} floors respectively could achieve better results for localization estimation. Such variation in methods would be due to the structure of each floor and the presence of obstacles.

Table 1: The antenna parameter for both Tx and Rx

Antenna properties	AP	Rx
Type of Antenna	Omni	Omni
Power (dBm)	30	-
Antenna Gain (dBi)	9	2
E-Plane HPBW	90°	90°
Waveform	Sinusoid	Sinusoid
VSWR	1	1

Table 2: The parameters utilized for each material within our case study

Materials	Thickness (m)	ε: σ
Concrete	30	5.31 : 0.066
Wood	4.5	1.99 : 0.012
Glass	0.3	6.27 : 0.012

Table 3: Comparison between the Actual coordination and the estimated from three proposed methods and for 2nd floor Rx points

Received Points	Second floor Actual Coordination		ToA/RSS Est. Coordination		AoA/RSS algorithm(Omni) Est. Coordination		AoA/RSS algorithm(Directional) East. Coordination	
	x	y	x	y	x	y	x	y
Rx1	25.6	19.30	25.13	19.57	25.75	19.63	25.15	19.53
Rx2	21.29	19.23	21.16	19.01	21.22	19.51	21.30	19.33
Rx3	1533	20.39	15.29	20.18	15.22	20.41	15.75	20.36
Rx4	7.49	20.28	7.21	20.41	7.52	20.36	7.49	20.33
Rx5	3.91	8.39	3.99	8.52	3.92	8.33	3.92	8.34
Rx6	17.53	7.97	17.66	7.81	17.64	7.85	17.61	7.94
Rx7	25.27	7.42	25.08	7.42	24.65	7.87	34.46	4.13
Rx8	29.67	3.18	29.81	3.76	29.23	3.41	39.24	3.06
Rx9	34.08	2.74	34.18	3.40	34.23	2.53	43.34	2.02
Rx10	44.60	14.22	44.96	14.38	45.11	14.03	54.61	30.24
Rx11	-13.62	17.58	-13.85	17.28	-13.58	17.72	-17.29	10.18

Table 4: Comparison between the Actual coordination and the estimated from three proposed methods and for 3rd floor Rx points

Received Points	Third floor Actual Coordination		ToA/RSS Est. Coordination		AoA/RSS algorithm(Omni) Est. Coordination		AoA/RSS algorithm(Directional) East. Coordination	
	x	y	x	y	x	y	x	y
Rx1	25.13	19.14	24.94	19.61	25.17	19.15	24.95	19.07
Rx2	21.41	18.97	21.74	18.72	21.29	19.18	21.52	19.01
Rx3	11.60	18.68	11.56	18.80	11.68	18.82	11.68	18.82
Rx4	-0.81	20.48	-0.95	20.24	-0.75	20.97	-0.82	20.81
Rx5	4.15	7.88	4.20	7.85	4.20	7.57	4.20	7.57
Rx6	32.10	7.45	22.83	7.31	23.03	7.50	28.67	7.59
Rx7	29.87	2.96	29.65	3.08	29.83	3.12	53.28	2.77
Rx8	34.24	2.61	34.14	2.33	34.44	2.36	40.09	2.98
Rx9	-6.57	20.09	-6.51	20.33	-6.26	20.67	-10.68	23.06
Rx10	-13.73	16.91	-14.05	16.02	-13.79	16.94	-17.96	7.52

Table 5: Ranging error values obtained from each method for 2nd floor Rx points

Rx Points	ToA/RSS		AoA/RSS Omni		AoA/RSS Directional	
	ToA/RSS (x)	ToA/RSS (y)	AoA/RSS (x)	AoA/RSS (y)	AoA/RSS (x)	AoA/RSS (y)
1	0.127	0.496	0.106	0.2700	0.3276	0.2269
2	0.135	0.072	0.007	0.2123	0.2807	0.1006
3	0.043	0.107	0.417	0.2048	0.0190	0.0279
4	0.279	0.036	0.003	0.1346	0.0772	0.0539
5	0.076	0.003	0.009	0.1262	0.0605	0.0489
6	0.121	0.109	0.078	0.1565	0.1190	0.0270
7	0.187	0.619	9.189	0.0069	0.4532	3.2802
8	0.133	0.440	9.567	0.5758	0.2347	0.1185
9	0.100	0.151	9.259	0.6583	0.2119	0.7211
10	0.362	0.510	10.011	0.1614	0.1979	16.0169
11	0.230	0.041	3.671	0.2964	0.1428	6.7658

Table 6: Ranging error values obtained from each method for 3^{3d} floor Rx points

Rx Points	ToA/RSS		AoA/RSS Omni		AoA/RSS Directional	
	ToA/RSS (x)	ToA/RSS (y)	AoA/RSS (x)	AoA/RSS (y)	AoA/RSS (x)	AoA/RSS (y)
1	0.189	0.477	0.039	0.014	0.177	0.068
2	0.330	0.252	0.117	0.209	0.113	0.042
3	0.036	0.120	0.077	0.142	0.078	0.142
4	0.144	0.240	0.054	0.498	0.018	0.335
5	0.058	0.031	0.053	0.311	0.053	0.311
6	0.277	0.135	0.075	0.056	5.566	0.143
7	0.220	0.115	0.042	0.155	5.401	0.191
8	0.104	0.279	0.204	0.251	5.846	0.373
9	0.066	0.245	0.315	0.585	4.112	2.970
10	0.324	0.894	0.061	0.030	4.231	9.389

Table 7: Comparison between Min. & Max. Ranging error obtained from the three proposed algorithms for all Rx points (a) 2nd floor Rx and (b) 3^{3d} floor Rx

(a)						
Rx Points	ToA/RSS		AoA/RSS Omni		AoA/RSS Directional	
	ToA/RSS (x)	ToA/RSS (y)	AoA/RSS (x)	AoA/RSS (y)	AoA/RSS (x)	AoA/RSS (y)
Min	0.043	0.003	0.003	0.007	0.019	0.027
Max	0.362	0.619	10.011	0.658	0.453	16.017

Table:7 Continued　　　　　　　　　　　　　**(b)**

Rx Points	ToA/RSS		AoA/RSS Omni		AoA/RSS Directional	
	ToA/RSS (x)	ToA/RSS (y)	AoA/ RSS (x)	AoA/ RSS (y)	AoA/ RSS (x)	AoA/ RSS (y)
Min	0.036	0.031	0.039	0.014	0.018	0.042
Max	0.330	0.894	0.315	0.585	5.846	9.389

5. Conclusion

In this work, a comparison between three proposed localization algorithms for indoor communication has been analyzed. These three algorithms include (ToA/RSS), (AoA/RSS Omni), and (AoA/RSS Directional), respectively. Results of these parameters were obtained from WI software, which has been used to model, simulate and investigate the wireless signal propagation characteristics within our case study building. Furthermore, the Matlab program has been used for designing and performing these hybrid algorithms. The analysis results indicate that using AoA/RSS with directional antenna could achieve the optimum coordination estimation with the antenna radiation pattern's point. In contrast, such a method shows ineffectiveness in handling the Non-Line of Site (NLOS) and far points. However, using the same method with an omnidirectional antenna has shown higher emphasis on localization at all points. Meanwhile, using ToA/RSS method for localization has shown significant results with realistic coordination estimation for far distributed points. As a result, using both ToA/RSS and AoA/RSS with an Omnidirectional antenna could be considered the most reliable method for our targeted building and achieving the optimum coordination estimation with lower ranging error.

Author contribution

All authors contributed equally to this work.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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