Evaluation of Indoor Position Localization System by Angle of Arrival Using RSS Based Distance Measurements

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Abstract. Indoor localization is a technique utilized to estimate the locations of objects and persons tracking. Time of Arrival (ToA) and Recieved Signal Strength (RSS) are the most too important techniques use for such tasks according to its easy implantation and acceptable accuracy. In this paper, AoA is utilized to estimate targets that are deployed in a selected case study building. Wireless InSite (WI) packages are utilized to simulate the case study model and apply our experiment. ToA and RSS are used to estimate distances between the transmitter and each target, then AoA is applied to locate each target. The results show that the errors between actual and estimated distance are in the range of (0 - 1) and (0.07 - 7.4) for ToA and RSS respectively. The achieved results show that AoA is an effective technique for indoor localization.

Keyword - AoA; ToA; RSS; Indoor localization; Wireless InSite.

1 Introduction

Modern developments in electronic technology and communication have resulted in the emergence of new applications in different fields including wireless communication with prospective applications. The most applications included environmental monitoring, military services, objective tracking, patient monitoring and tracking [1]. Location-based services (LBS) involve the localization process of finding the target position [2]. In many applications of wireless communication, including tracking and monitoring, the collected data is still not very much useful without knowing the corresponding target positions. In recent years the Indoor Positioning System (IPS) utilizing the radio signal has developed rapidly due to increasing demands for indoor Location-Based-Devices (LSB) [3], [4].

Localization techniques can be divided into range-based and range-free schemes. The first one is widely used due to its high accuracy, ease of implementation and applicability to different radio technologies. Range (distance) estimated from different features of the received radio signal, like time of arrival (ToA), time of flight (ToF), time-difference of arrival (TDoA) and received signal strength (RSS) [5].

RSS is a method to estimate the position location of a target, the distance between two points can be estimated by measuring the energy of the received signal at one end. Distance calculation based on RSS measurements requires the knowledge of channel characteristics. The RSS can be classified to a constant and a variable component. The constant component is affected by a path loss propagation model, and the variable component is affected by many factors include multipath effects, signal attenuation and shadowing. RSS method is highly accurate in short-range and Line-of-Sight (LoS) environment. In addition, it's easier, cheaper

and does not require time synchronization. However, the RSS method requires at least three reference points to locate the position of a target. Moreover, the power control used in measurements seriously affects the accuracy and can lead to incorrect target positioning. Also, this method does not work perfectly in Non-Line-of –Sight (NLOS) state because of multipath effects [6].

The second important technique for localization positioning is range free which includes distance-vector hop, fingerprint matching and Angle of Arrival AoA measurement [7]. AoA is an example of range free which is represents the angle between an incident wave propagation direction and some reference direction which is called orientation. Orientation, defined as a fixed direction against which the AoA are measured, is represented in degrees in a clockwise direction. AoA determines the direction based on the measurement of TDoA at individual elements of the array, from these delays the AoA can be estimated.

There are many challenges facing indoor localization such as huge and large noise and multipath from other wireless communication like cellular system communication [8]. Inaccuracies in measurement of AoA can be related to the wireless communication channel, the measuring device/method, or both. The spatial features of the wireless channel have a significant effect on the AoA detection [9].

Many researchers reviewed the subject of indoor localization using many techniques such as [8] who present an evaluation of the performance of received power level versus the separation distance between the access points to every received point in four selected locations. The results showed a significant variation from the four determined locations, this variation is related to reflection of different obstacles in indoor environment and different materials effects on signal wave propagation. In [10] where AoAs were estimated by finding the mean received power and determine the mean time of arrival (ToA) to obtain orientation and theta for butter localization in an antenna array. Also, [11] proposed an AoA-based localization with two known access point 4800 Wi-Fi with 2.4 GHz to estimate the location for 10 unknown points were used for more accurate result and the localization error was less than 2.5 meter, about 80% of the time as the result showed in the Line of Sight (LoS) dominating environments. In [2] researchers present an approach for localization using the RSSI values. The method was applied in a 5 x 4 m indoor environment an average two dimensions localization error of 30 cm is obtained. In this paper, one building of Electrical Engineering Technical College is selected as a case study to apply an experiment position location for many objects represented by the receiver device (RXs). Also, the number of transmitter device (TXs) is installed in a preplanned location in order to obtain AoA measurement and RSS estimation.

2 AoA Based Position Localization

In wireless communication system the AoA estimated the position location in 3D, to calculate the distance between the source and the target according to the speed of electromagnetic wave propagation in indoor environment by mean time of arrival, the distance d is obtained by:

$$d = c \times t \tag{1}$$

Where c is speed of light (3×10^8) ms^{-1}, t is the propagation time in one way signal with maximum power received [10].

The source and target separation distance can be utilized to determine the coordinates of the location of target which is represented as target. Such location will be determined with respect of source location and bearing angle β between source and target which represented by the relation:
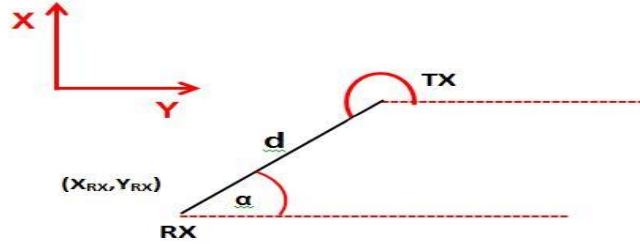
$$\beta = \alpha + \pi. \tag{2}$$

Where α is direction of arrival in (phi) calculated by Wireless InSite (WI) package as a position coordination of target (X_{RX}, Y_{RX}) which can be estimated by:

$$X_{RX} = X_{TX} + d \times \cos(\beta) \tag{3}$$

$$Y_{RX} = Y_{TX} + d \times \sin(\beta) \tag{4}$$

Where (X_{TX}, Y_{TX}) represented the TXs known location, equations (3) and (4) are clear out in **Figure** 1 [12].

Fig. 1. RX coordinates with respect to TX position.

3 RSS based distance measurement

RSS is the strength of a received signal measured at the receiver's antenna. RSS is determined by the transmission power, the distance between the transmitter and the receiver, and the radio environment. All wave signals suffer from phenomena called free-space loss [13] in which the signal becomes weaker as a function of distance squared when propagates in space. The received power can be calculated according to Friis equation:

$$P_r = \frac{P_t\ G_r\ G_t \lambda^2}{(4\pi)^2\ d^2} \tag{5}$$

Where P_t is the transmitted power, G_t and G_r are the antenna gain of the transmitter and receiver respectively, λ is the carrier wavelength it is equal to:

$$\lambda = \frac{f}{c} \tag{6}$$

Where λ is the wavelength of the signal and f is the carrier frequency of the signal.

The propagated signals are subjected to various types of attenuations called path loss parameter which can be calculated by [14], [18]:

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) - G_t - G_r \tag{7}$$

Where d is the distance between transmitter and receiver.

To estimate the distance between the transmitter and receiver coordinator can be based on equation [19]:

$$d = 10^{-(RSS - P_t + Pl_0 - \sigma)/10\,\gamma)} \tag{8}$$

Where Pl_0 (FSPL) is the path loss at a reference distance do (1 meter) and by applying equation (7) found to be equal to (32.64dB), the path loss exponent γ depends on the environment and which is in a range of $(2 - 6)$, according to [20]. In this paper, γ is considered as (4). Also, according to [20], [21], the standard deviation σ depended on the environments of case study in the range of $(2 - 14)$ which assumed to be (9) in this paper.

4 Case Study

The 1'st floor of case study building, with a dimension of (47.5m×43.5m×3.5m) is chosen to apply our experiment. Firstly, the simulated building is designed using WI packages and loaded by specific instructions. The resultant building is illustrated in **Figure 2(a)**. Three different locations of TXs device with a height of 2m above the floor are set up in various locations highlighted by black color. On the other hand, twenty RXs with 1.5m above floor are distributed randomly on the same floor of the building shown as red color in **Figure 2(b).** Also, all properties of both TX and RX are listed in Table 1.

Additionally, the impact of different building materials (Concrete, Glass, Wood and Brick) on wave propagation with a frequency of 2.4GHz band and 1MHz bandwidth was taken into consideration for the entire investigation. Each material thickness, conductivity (σ) and relative permittivity (η`) was determined based on the recommendation of the International Telecommunication Union (ITU). The results of ($\sigma$ & $\eta$`) calculations at a frequency of 2.4 GHz are listed in Table 2 [22].

● TXs

● RXs
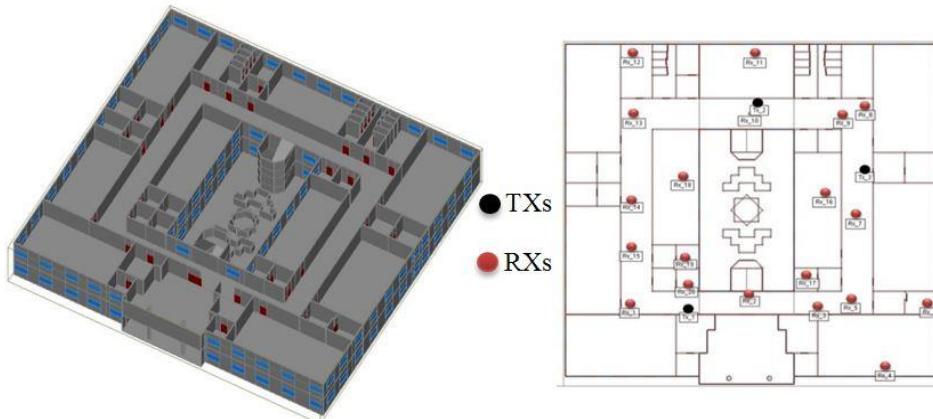
(a)   (b)

Fig. 2. Simulation model of case study building (a) 3D view

(b)   TXs and RXs locations.

Table 1. TX and RX antenna properties.

| Antenna properties	TX Antenna	RX Antenna
Antenna type	Omni-Directional	Omni-Directional
Input Power (dBm)	6	-
Gain (dBi)	5.4	2
Waveform	Sinusoid	Sinusoid
Polarization	V	V
(VSWR)	1	1

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

Table 2. Material Thickness, Conductivity and Permitivity values.

Materials	Thickness (m)	σ	$\eta`$
Concrete	0.125	0.066	5.31
Glass	0.003	0.012	6.27
Wood	0.030	0.012	1.99
Brick	0.125	0.038	3.75

5 Results and Discussion

As with previous explanation of sections 2 and 3, the location can be estimated by only one TX when depending on equations (3) and (4), but for more accuracy, three TXs are deployed. The estimated distance using Wireless InSite (WI) package based on mean time of arrival, while the estimated distance based on RSS values obtained according to equation (8). The RSS values determined using Wi-Fi meter application. There was a slight difference in distance measurement in both ways, this difference can be explained by the fact that the RSS measurement affected by multipath effects, signal attenuation and shadowing. In addition to indoor environment infrastructure for example (Objects, Furniture, Forner, Other electrical and electronic devices, etc), this difference can be noticed in **Figure 3.** which illustrates the estimated distance based on mean ToA and RSS simultaneously.
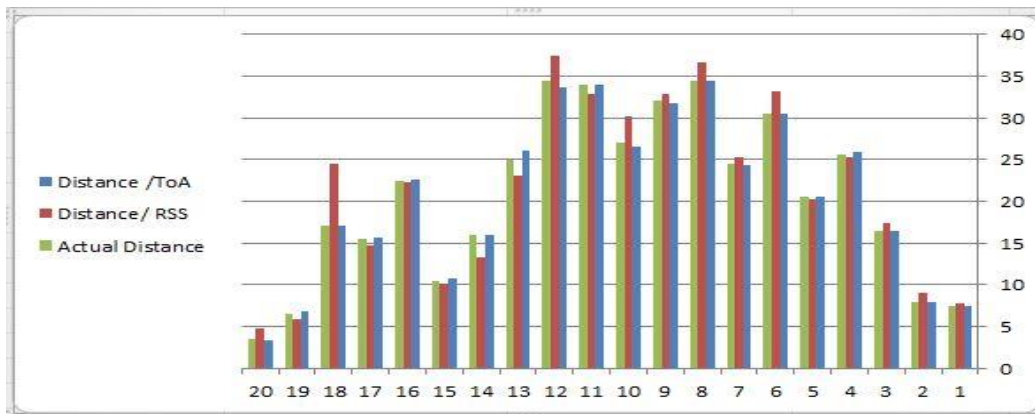
(a)
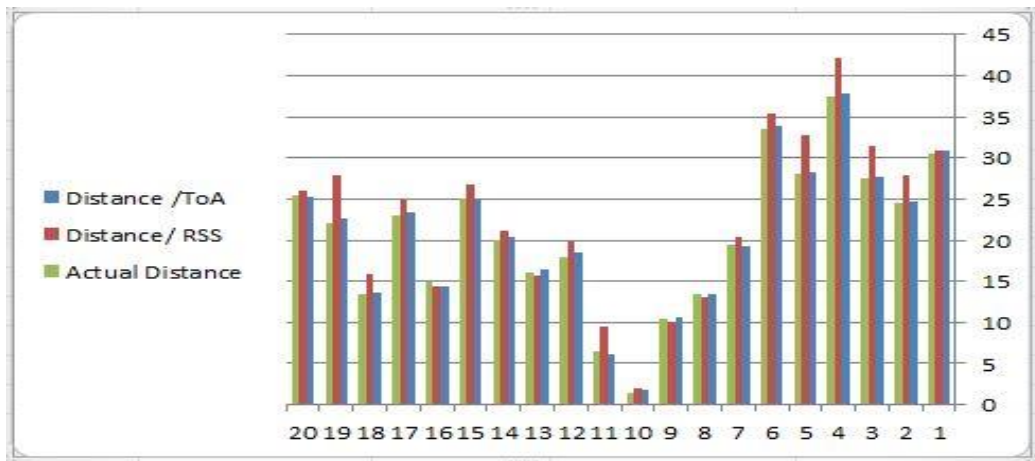
(b)
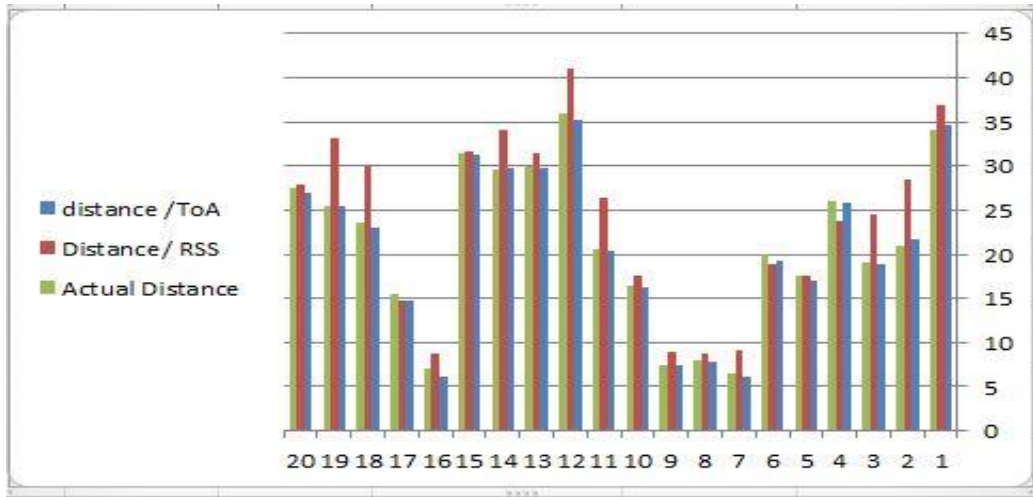
(c)

Fig. 3. Estimated distance based on Mean ToA and RSS in:

(a) TX-1, (b) TX-2 and (c) TX-3.

As illustrated in Table 3**.** The RSS based distance error was estimated and maximum error value found to be (7.4, 5.9, 7.7) meter in TX-1, TX-2 and TX-3 respectively These slight errors in distance estimation is due to indoor environment infrastructure. On the other hand, the maximum value for ToA based distance error was (1, 0.6, 0.9) meter in TX-1, TX-2 and TX-3 respectively.

Table 3. Showed the estimated distance based on mean ToA and RSS with distance error for (a) TX-1,

(b) TX-2 and (c) TX-3.

Tx-1	location	(15.5, 8.5)					
Receives	α	Distance /ToA	Pr	Distance/RSS	Actual Distance	Distance Errors /ToA	Distance Errors /RSS
Rx_1	355.74	7.5	-53.3	7.7893	7.5	0	0.289
Rx_2	194.88	7.9	-55.7	8.9433	7.9	0	1.043
Rx_3	180.59	16.5	-67.2	17.338	16.5	0	0.838
Rx_4	163	25.9	-73.7	25.206	25.6	0.3	0.394

Receives	α	Distance /ToA	Pr	Distance/ RSS	Actual Distance	Distance Errors /ToA	Distance Errors /RSS
Rx_5	183.29	20.5	-69.9	20.253	20.5	0	0.247
Rx_6	181.38	30.5	-78.5	33.228	30.5	0	2.728
Rx_7	211.47	24.3	-73.8	25.351	24.5	0.2	0.851
Rx_8	229.83	34.4	-80.2	36.644	34.5	0.1	2.144
Rx_9	233.94	31.8	-78.3	32.847	32	0.2	0.847
Rx_10	253.66	26.5	-76.8	30.13	27	0.5	3.13
Rx_11	256.53	33.9	-78.3	32.847	34	0.1	1.153
Rx_12	282.68	33.7	-80.6	37.497	34.5	0.8	2.997
Rx_13	285.48	26	-72.2	23.121	25	1	1.879
Rx_14	297.43	15.9	-62.5	13.228	16	0.1	2.772
Rx_15	313.2	10.7	-57.8	10.093	10.5	0.2	0.407
Rx_16	221.35	22.6	-71.6	22.336	22.5	0.1	0.164
Rx_17	197.15	15.6	-64.3	14.672	15.5	0.1	0.828
Rx_18	272.83	17.1	-73.2	24.491	17	0.1	7.491
Rx_19	274.46	6.8	-48.5	5.9088	6.5	0.3	0.591
Rx_20	276.12	3.3	-44.5	4.6935	3.5	0.2	1.194

(a)

Tx-2	Location	(24.5 , 35.5)					
Receives	α	Distance /ToA	Pr	Distance/ RSS	Actual Distance	Distance Errors /ToA	Distance Errors /RSS
Rx_1	57.75	30.9	-77	30.832	31	0.4	0.3318795
Rx_2	91.86	24.74	-75	27.797	25	0.24	3.29713268
Rx_3	106.32	27.64	-78	31.369	28	0.14	3.8689513
Rx_4	114.99	37.8	-83	42.073	38	0.3	4.57266284
Rx_5	114.16	28.2	-78	32.847	28	0.2	4.84732443
Rx_6	131.93	33.9	-80	35.4	34	0.4	1.89973411
Rx_7	130.44	19.3	-70	20.37	20	0.2	0.87042078
Rx_8	177.4	13.4	-62	13.152	14	0.1	0.34775168
Rx_9	171.01	10.7	-58	10.151	11	0.2	0.34920633
Rx_10	47.57	1.8	-30	2.0725	1.5	0.3	0.57252606
Rx_11	275.28	6.2	-57	9.528	6.5	0.3	3.02796164
Rx_12	30.75	18.5	-70	19.792	18	0.5	1.79247021
Rx_13	5.94	16.5	-66	15.722	16	0.5	0.27828208
Rx_14	37.62	20.4	-71	21.208	20	0.4	1.20801393
Rx_15	50	24.9	-75	26.853	25	0.1	1.85344446
Rx_16	125.28	14.4	-64	14.338	15	0.6	0.66162284

Rx_17	108.29	23.3	-74	24.917	23	0.3	1.91724371
Rx_18	45.13	13.7	-66	15.904	14	0.2	2.40376684
Rx_19	66.46	22.6	-76	27.958	22	0.6	5.95760728
Rx_20	69.5	25.2	-74	25.942	26	0.3	0.44179362

(b)

Tx-3	location	(38,26.5)					
Receives	α	distance /ToA	pr	Distance/ RSS	Actual Distance	Distance Errors /ToA	Distance Errors /RSS
Rx_1	31.46	34.6	-80	36.8553	34	0.6	2.8553
Rx_2	54.2	21.7	-76	28.44461	21	0.7	7.44461
Rx_3	71.6	18.8	-73	24.49063	19	0.2	5.49063
Rx_4	95.59	25.8	-73	23.79578	26	0.2	2.20422
Rx_5	83.87	17	-68	17.64006	17.5	0.5	0.14006
Rx_6	114.5	19.3	-69	18.90166	20	0.7	1.09834
Rx_7	78.77	6.1	-56	9.204496	6.5	0.4	2.7045
Rx_8	269.6	7.8	-55	8.73977	8	0.2	0.73977
Rx_9	291.6	7.4	-56	8.994976	7.5	0.1	1.49498
Rx_10	334.3	16.3	-67	17.53881	16.5	0.2	1.03881
Rx_11	313.8	20.3	-75	26.39368	20.5	0.2	5.89368
Rx_12	25.03	35.2	-82	41.11497	36	0.8	5.11497
Rx_13	346.7	29.7	-78	31.36895	30	0.3	1.36895
Rx_14	7.42	29.8	-79	34.00165	29.5	0.3	4.50165
Rx_15	21.34	31.3	-78	31.73219	31.5	0.2	0.23219
Rx_16	32.14	6.1	-55	8.73977	7	0.9	1.73977
Rx_17	61.77	14.8	-65	14.84226	15.5	0.7	0.65774
Rx_18	4.41	23.1	-77	29.95712	23.5	0.4	6.45712
Rx_19	27.12	25.4	-79	33.22768	25.5	0.1	7.72768
Rx_20	34.79	27	-76	27.95761	27.5	0.5	0.45761

(c)

In Table 4, ToA and RSS based distance utilized to determine each receiver coordinates using equation (3) and (4), and the results show that ToA based AoA location determination was slightly more accurate than RSS based method.

Table 4. Position localization ToA and RSS based AoA estimated.

Tx-1	location	(15.5, 8.5)								
	Estimated Location AoA /ToA		Estimated Location AoA / RSS		Actual Location		Errors AoA / ToA		Errors AoA / RSS	
Receive	X	Y	X	Y	X	Y	X	Y	X	Y
Rx_1	8.02	9.06	7.8	9.07	8	9	0.02	0	0	0
Rx_2	23.1	10.51	23.13	10.51	24	10.5	0.4	0	0	0
Rx_3	32	8.64	31.7	8.64	32	8.7	0.2	0	1	0
Rx_4	40.2	0.92	39.5	1.13	41	1	0.3	0	1	0
Rx_5	35.9	9.67	35.6	9.62	36	9.75	0.1	0	0	0
Rx_6	45.9	9.03	46.2	9.46	46	9	0.1	0	0	0
Rx_7	36.2	21.16	37	21.68	37	20.5	0.3	1	1	1
Rx_8	37.7	34.7	39.1	36.46	38	34.5	0.3	0	1	2
Rx_9	34.37	34.2	34.8	35	35	33.6	0.83	1	0	1
Rx_10	22.9	33.9	23.9	37.3	23	34	0.4	0	1	3
Rx_11	23.4	41.46	23.15	40.3	24	41.5	0.6	0	1	1
Rx_12	8.26	41.38	7.34	44.9	8	41.5	0.04	0	1	3
Rx_13	8.59	33.55	9.3	30.7	9	33.5	0.09	0	1	3
Rx_14	8.18	13.25	9.4	20.2	8	22.7	0.22	9	1	3
Rx_15	8.17	16.29	8.65	15.7	8	16.4	0.03	0	0	1
Rx_16	32.4	23.4	32.26	23.2	33	23.5	0.3	0	0	0
Rx_17	30.4	13	29.45	12.7	31	13.5	0.1	1	1	1
Rx_18	14.9	25.57	14.2	32.8	15	25.5	0.2	0	1	7
Rx_19	15.04	15.2	14.8	14.3	15	15	0.04	0	0	1
Rx_20	15.15	11.7	15.01	13	15	11.8	0.05	0	0	1

From all previous error, it is clear that both RSS and ToA is effective algorithm to estimate the distance between transmitter and targets. But ToA is slightly better RSS according to the fluctuation of the received signal due to many sources of noise. Like mobile network, wireless local area network and other electric devices.

5 Conclusions

In this paper, a case study of a selected building is simulated using WI software package in order to estimate the locations of many targets. For such an experiment, 20 receivers represent such targets are deployed randomly in the case study area. AoA algorithm is utilized to estimate the target locations which need a distance between the transmitter and target in addition to the angle between an incident wave and reference direction. The distances are estimated in two methods ToA and RSS in order to compare between them to approach accurate estimation. The results confirm that ToA is slightly better than RSS for indoor localization. The resultant errors between actual and estimated locations are in the range of (0.8, 0.6) for ToA and the range of (1.1, 7.3) for RSS methods.

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