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Comparative evaluation of localization range-free algorithms in wireless sensor networks

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Abstract

Localization in wireless sensor networks is essential not only for determining the location but also for routing, managing density, tracking, and a wide range of other communication network functions. There are two main categories of localization algorithms in wireless sensor networks: range-based algorithms and range-free techniques. Localization based on range-free algorithms has benefits in terms of requiring less hardware and energy, making it cost-efficient. This paper examines the impact of beacon nodes on range-free localization algorithms. The findings indicate that ADLA has intermediate localization errors and the best detecting nodes. It also addresses the effect of the number of locators on the algorithm's efficiency. The findings demonstrate that as the number of locators increased, the number of detected nodes in Centroid also increased. Compared to Centroid, ADLA has the second-best detecting nodes but with better average error. Moreover, it considers the impact of the number of static nodes on range-free localization algorithms, and ADLA achieved the best detection nodes. According to the evaluated results, this paper proposes a hybrid algorithm that combines the Centroid algorithm and Active Distributed Localization Algorithm (ADLA) algorithm. However, combining these two algorithms results in less localization error.

Keywords: Wireless sensor networks, range-free, average localization error, detected nodes

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1. Introduction

Several application domains can be addressed with the use of wireless sensor networks. Sensor networks that employ many mobile or stationary sensors work collaboratively to sense, gather, process, and transmit data in a self-organized and multi-hop fashion (Salama et al., 2023; Gao and Xu, 2023). Computers are changing rapidly and the future is not just the conventional desktop. With the advent of modern wireless communication, the Internet of Things (IoT) is becoming a new paradigm that is attracting a lot of attention. As part of this paradigm, objects in the environment will be a part of the network. Therefore, our information and communication systems are seamlessly integrated into our surroundings. Many objects around us can be identified using Radio-Frequency Identification (RFID) with other things such as tags, wireless sensors, actuators, and mobile phones. The IoTs concept relies on the ubiquitous presence of different objects around us. To accomplish a common objective, these objects will cooperate (Khan and Abbasi, 2016).

Localization algorithms in wireless sensors are classified into two key categories those are range-based and range-free algorithms. A range-based localization scheme and a range-free localization scheme both use anchor nodes (Aldeen et al., 2023; Kaur et al., 2023). It is easier and cheaper to implement the range-free algorithm because it only relies on connectivity between sensor nodes (Cui et al., 2023). The range-free computations include locations of anchors/beacons and hopdistances between nodes and founded on these, the location of a sensor can be estimated. As a result,the connectivity of nodes is necessary. Range-based localization algorithms have various limitations such as cost,additional hardware computational overhead, energy usage, precision, small range, and reliability. To defeat these limitations a variety of range-free algorithms have been proposed. Range-free localization algorithms have benefits in terms of less hardware and energy required and therefore, cost-efficient. Distributedlocalization algorithms areclassified into two wide classes exactly, beacon-based and signature-based techniques. The beacon-based systems require the existence of particular nodes that recognizetheir locations, named beacon nodes (Jadliwala et al., 2007; Zhong et al., 2007; Qian et al., 2011; Cabero et al., 2014; Cao and Xu, 2023).

2. Range Free System

The range-free technique achieves the location of non-anchor nodes according to contained information presented by anchor nodes, typically based on messages exchanged, normally called beacons. This information is frequently made up of diverse features, such as the number of hops flanked by devices or radio coverage associations (Lazos and Poovendran, 2006; Mohd et al., 2006; Ammar et al., 2010; Nabil et al., 2012; Farman et al., 2012; Samanta et al., 2013; Virmani and Jain, 2013). The quantity of associated anchor nodes is the most key variable influencing the execution of the location algorithm, paying little respect to whether it is run range-free or not. Progressively associated anchor nodes permit more prominent location precision. Be that as it may, the strategies to enhance the location exactness by expanding the number of associated anchor nodes in WSNs are not available (Jiang et al., 2018). Notably, the major benefit of range-free can reduce the error in terms of localization exclusive of any extra hardware price. On the other hand, the localization based on range free tends to estimate regular node's position using the signal transmitted by the locator as well as the signal transmitted by beacon nodes for its locations.

3. Algorithms Evaluation

Evaluating the comparative performance of the localization Range-free algorithm is significant for investigators both in authenticating a novel algorithm with the prior one or when selecting one of the existing algorithms to contain all requirements for specified applications of the wireless sensor network. Based on the preceding results this paper investigates the impact of the digit of beacon nodes, locators, and static nodes on the number of detected sensor nodes and localization errors then the hybrid algorithm is proposed. In all remaining sections of this paper, a Wireless Sensor Network Simulator v1 is used to plot the graph. In all figures, the Y axes represent the value of detected nodes or average localization errors.

3.1 The effect of Beacon Nodes on Range-Free Localization Algorithm

Singh and Khilar (2017) states that there are two major problems with the existing range-free localization method based on mobile beacons. The first one is the accuracy of position estimation which is greatly influenced by the broadcast interval of the beacon. The second problem is the localization accuracy that highly dependent on the radio propagation irregularities. Active Distributed Localization Algorithm (ADLA) is used to find the range of an un-localized node.In this algorithm, as the number of beacons increases the number of detected nodes is increased, but the number of average errors is slightly increased as shown in Figure1. Distributed localization algorithm (DIL) is an algorithm in which there are three kinds of nodes proposed namely, normal nodes without position information, beacon nodes with situation information, in addition toanchors or locator nodes with angled information. The beacon nodes are deployed in an arbitrarily manner more than the network together with locator nodes that are arranged arbitrarily. In this algorithm, the numeral of detected nodes israisedthe same as the number of beacons increases while the average errors are unstable as shown in Figure 2.

The High-Resolution Robust Localization (HiRLoc) system permits sensors to recognize their situation with towering precision even in the occurrence of defense threats. Nevertheless, this algorithm considers two categories of nodes, which are the locator/anchor nodes that pass on beacons with position information with unknown location regular nodes. This algorithm gives the best results in an average error when comparing with ADLA and the best-detected sensor nodes when comparing with DIL as shown in Figure 3. For the Restricted area-based Localization Algorithm (RAL), there are two kinds of nodes,the normal nodes along with anchors' nodes. RAL maintains average detected sensor nodes with the best average errors when compared with HiRLoc, and better average error when compared with RAL, and this comparison is done according to Figure3andFigure4. Lastly,the Secure Range-Independent Localization that is used for WSNs (SeRLoc) is described as a distributed algorithm that depends on a two-tier network structural design. It lets sensor nodes inactively decide their position with no help from other sensor nodes in the network. This algorithm gives high decreases in average errors with average detected sensor nodes with increasing the number of beacons as shown in Figure 5.

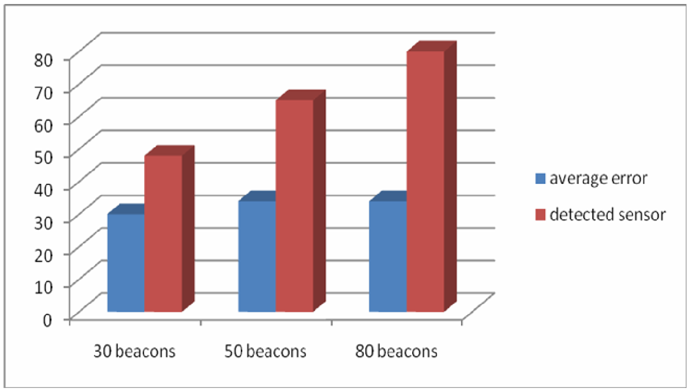

Figure 1: ADLA Efficiency Vs Number of Beacons

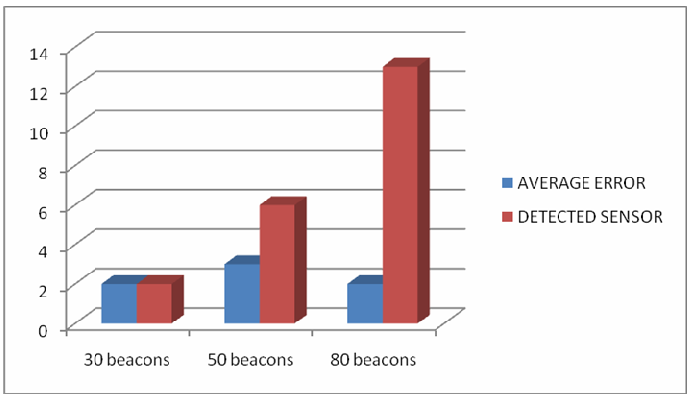

Figure 2: DIL Efficiency Vs Number of Beacons

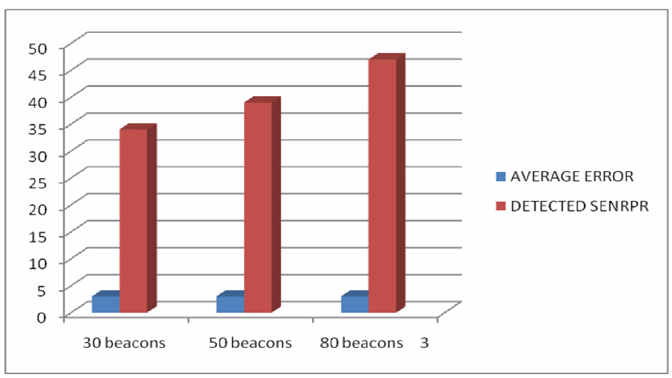

Figure 3: HiRLoc Efficiency Vs Number of Beacons

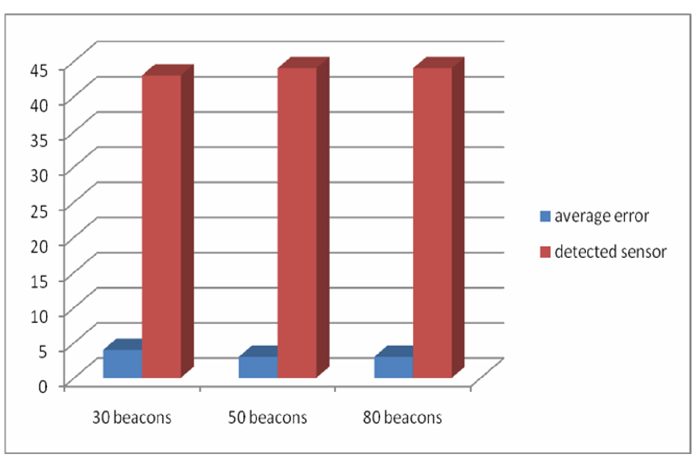

Figure4:RAL Efficiency Vs Number of Beacons

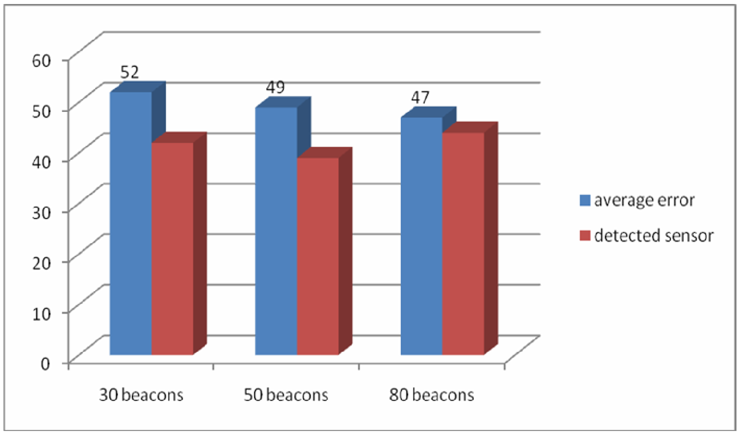

Figure 5:SeRLocEfficiencyVs Number of Beacons

3.2 Number of Locators and it is Effect on Algorithms Efficiency

A localization technique based on range-free techniques relies on relationships between nodes and topological data about sensor nodes (Nemer et al., 2021). In a centroid-based algorithm, every anchor first sends their situations to each sensor node surrounded by their transmission range. Therefore, all unknown nodes listen for a fixed period after that collect all the beacon signals they receive from a variety of reference points. Subsequently, all unknown sensor nodelocations are estimated by a centroid determination from all n locations of the anchors in range. The Centroid algorithm is shown in Figure 6 with a different number of locators. It is obvious with the increasing number of locators as the number of detecting nodes increases the average localization errors decrease and vice versa. The number of detecting nodes is increased to the highest value compared with other algorithms as the number of locators increases.

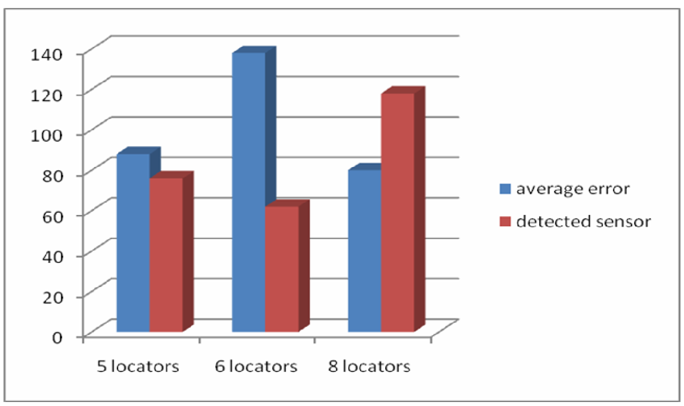

Figure 6: Centroid Efficiency vs. Number of Locators

The HiRLoc algorithm is different than the Centroid, as the number of locators increases all the detecting nodes and average localization errors are increased respectively as shown in Figure 7. However, the detecting nodes increase to high values with the increasing of number locators.

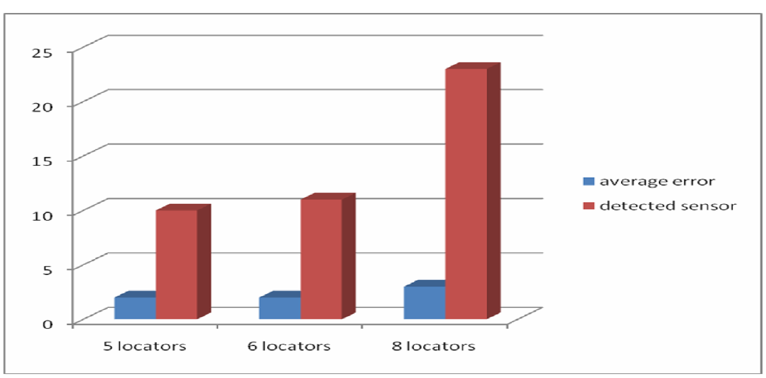

Figure 7:HiRLoc Efficiency Vs Number of Locators

For RAL the number of detected nodes increases to more than double when increasing the number of locators from five to six. However, it increased to double and half when the number of locators increased from six to eight. The average error is variegated but better when using less number of locators as shown in Figure 8.

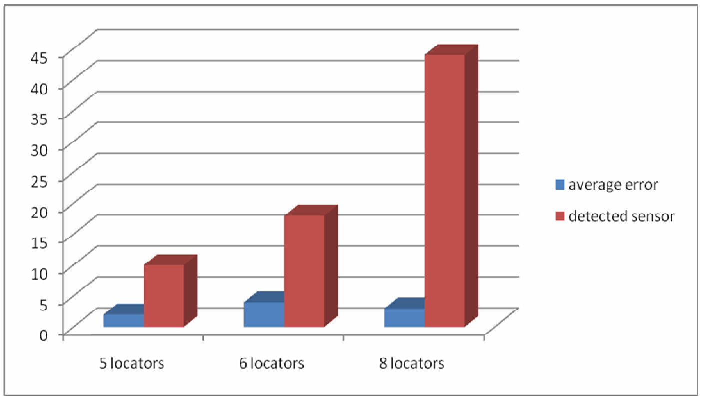

Figure 8: RAL Efficiency Vs Number of Locators

Figure 9 shows the plot of the ADLA algorithm. The number of detected nodes is increased by increasing the number of locators. The average localization errors are somewhat similar at any time in which the number of locators increases.

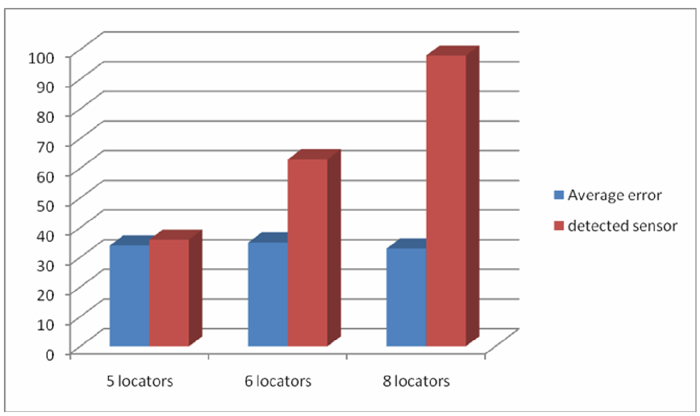

Figure 9: ADLA Efficiency Vs Number of Locators

The SeRLoc algorithm is evaluated by using various numbers of locators. It shows that the number of detected nodes when using five or six locators the difference is not big. But by using eight locators the number of detected nodes is increased sharply. Here, the average localization errors are fairly vary in value any time the number of locators increases as shown in Figure 10.

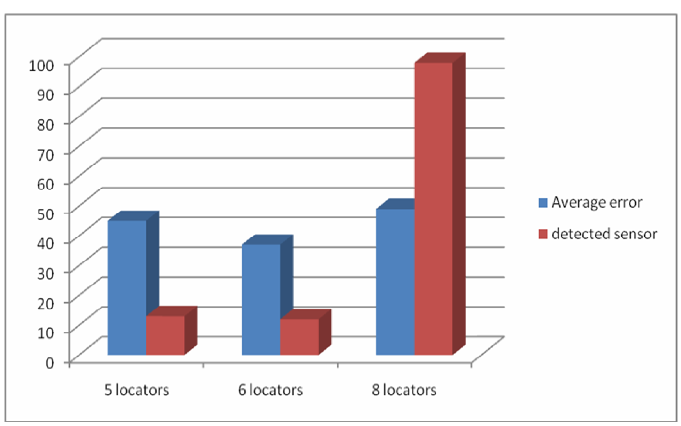

Figure 10: SeRLoc Efficiency Vs Number of Locators

Finally, Figure 11 shows that DIL efficiency is better in case of number of detected nodes is eight times when using eight locators than using five or six locators. However, the average localization error rate varies but is best when using six locators

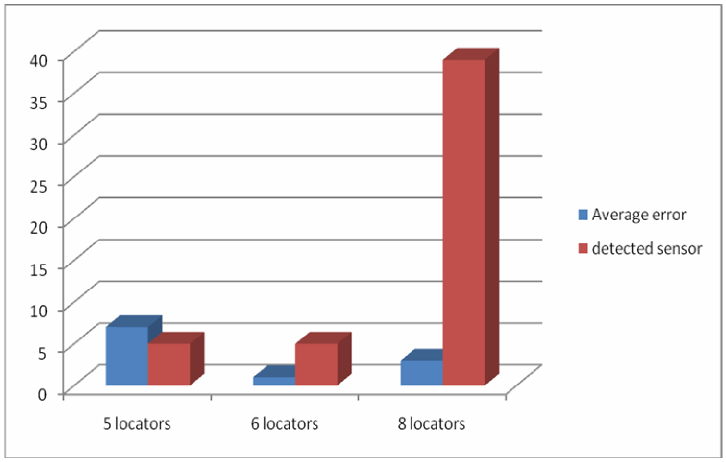

Figure 11: DILEfficiency Vs Number of Locators

The number of locators and theireffect on algorithm efficiency is summarized in Table 1, in which the average error is abbreviated as avg. and the detected sensor node by SN.

Table 1: compares the number of detected nodes and average localization error

Algorithm / No. of Locators	Centroid		HiRLOC		RAL		ADLA		SeRLoc		DIL	
	Avg.	D.N	Avg.	D.N	Avg.	D.N	Avg.	D.N	Avg.	D.N	Avg.	D.N
5	80	65	1.6	8	2	7	27	30	38	10	5	4
6	130	55	1.7	9.5	7	15	28	57	31	9	1	4
8	70	108	2.5	22	4	41	27	93	42	92	2.5	36

3.3 Number of Static Nodes Deployed in Area and it is Effect on Algorithms Efficiency

Zhang et al. (2010) used Sequential Monte Carloto evaluate the energy-efficient Range-Free localization and they tested their algorithm in real-world deployments of static sensor networks to validate its performance results. To evaluate the effect of the number of static nodes on the algorithm efficiency based on the above-mentioned statement, a wireless simulator is first run with a hundred static nodes and then with two hundred nodes as shown in Figures 13 and 14 respectively. Comparing the result of the two figures, it is found that as the number of static nodes increased the average location error (avg.) decreased except for RAL which is compatible with the Nabil et al. (2012) report that RAL & DIL have a low possibility of location detection. On another hand by increasing the sum of static nodes the numeral of detected sensor nodes (SN) is also increased except for RAL and Centroid as shown in Figures 12, and 13 summarized in Table 2.

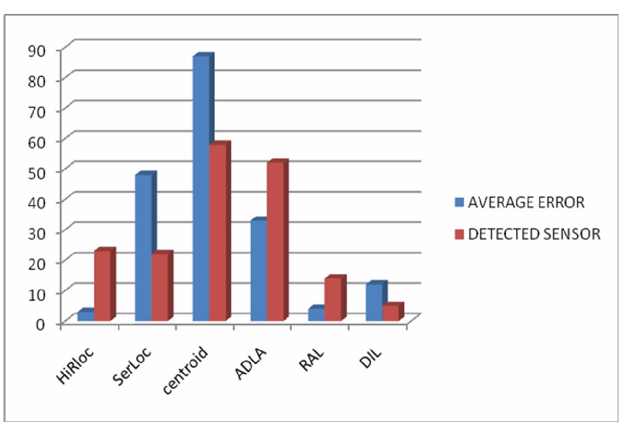

Figure 12: Range free algorithms efficiency vs 100 static sensor nodes

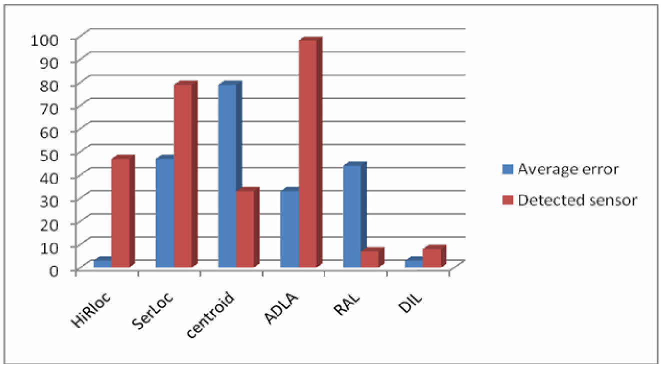

Figure 13: Range Free Algorithms Efficiency Vs 200 Static Sensor Nodes

Table 2: Compares the number of detected nodes and average localization error

Algorithm / No. of Static Sensor	HiRLOC		SeRLoc		Centroid		ADLA		RAL		DIL	
	Avg.	D.N	Avg.	D.N	Avg.	D.N	Avg.	D.N	Avg.	D.N	Avg.	D.N
100	2.5	21	45	20	84	55	31	50	30	11	10	4
200	2	44	43	75	75	30	30	93	40	5	2	6

4. Hybrid Proposed Algorithm

In a hybrid algorithm, a combination of theCentroid algorithm and ADLA algorithm is proposed. However, centroid algorithms have a high localization error and a fine number of detected sensor nodes, while the ADLA algorithm has a better proportion of detected sensor nodes and a good localization error when comparedwiththe centroid.

4.1 Wireless Sensor Network Simulator

With so many simulators available, choosing one is a challenge and depends primarily on how easy it is to use, and how well it meets the requirements of the model. Remarkably, different simulators do not give similar results for the same model due to their different underlying features and implementations (Fahmy, 2023). A framework for localization in WSNs that combines range-free, range-based, and hybrid algorithms is designed and implemented to analyze a wide range of localization schemes (Edam et al., 2022). Here, a Wireless Sensor Network Simulator V1.1 is used to simulate the WSN. However, many parameters can be considered when deploying a network such as random locators, static sensors, mobile sensors, and beacon nodes. Various network parameters are listed in Table 3 with their values used in simulations.

Table 3: Wireless Sensor Network Simulator parameters

No.	Item	Quantity
1.	Number of Random Locators	8
2.	Number of static sensors	200
3.	Number of mobile sensors	20
4.	Number of beacon nodes	50
5.	Path loss	2
6.	Variance	1
7.	Mean	0

4.2 Wireless Sensor Network Deployment

The configuration sliders can be used to set the properties of the network. The network configuration properties fall under two groups, which are deploying the network and running simulations. The first one controls the hardware possessions of the network such as the number of nodes in the network. While the second one defines the software properties of the network as shown in Figure 14.

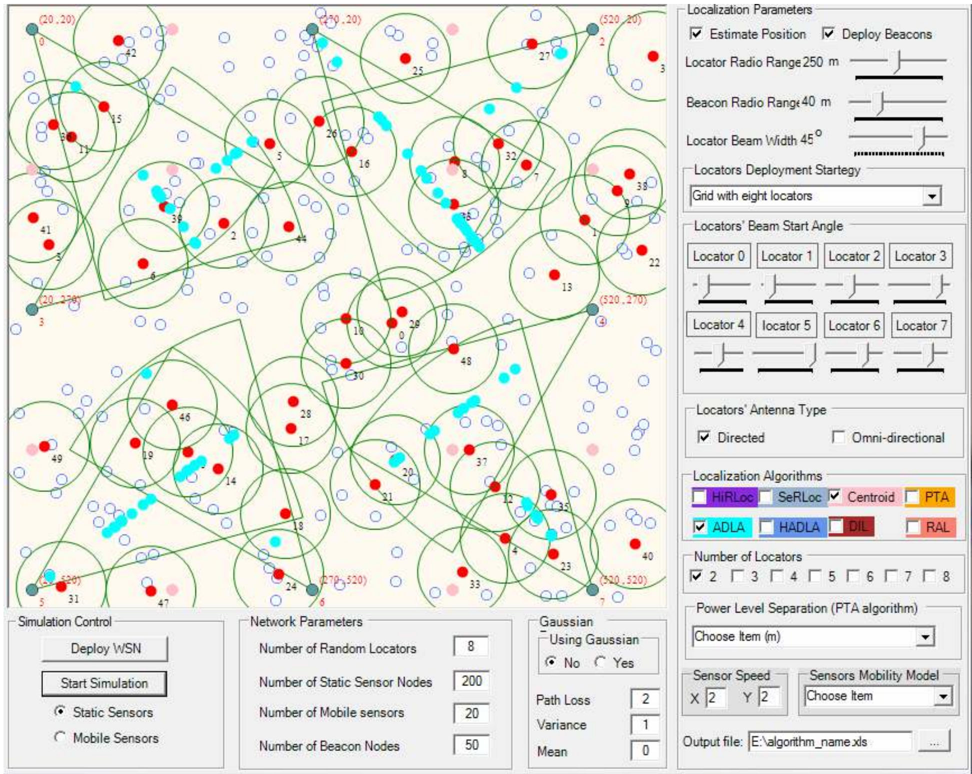

Figure 14: Hybrid Proposed Algorithm Simulation

The Centroid has the highest number of detected sensor nodes of all evaluated algorithms with a somewhat high average localization error. ADLA also has a high number of detected sensor nodes and medium average localization error among the algorithm of low possibility of location detection. Therefore, the hybrid proposed algorithm attempts to maintain the high degree of detection of sensors and reduce the average localization error. Thus, combining these two algorithms gives a better localization error compared to individual algorithm error as shown in Figure 15. However, the two algorithms have a superior percentage of detected sensor nodes as evaluated in previous sections.

Figure 15: Hybrid proposed Algorithm vs. Centroid and ADLA.

The modified algorithm regards two kinds of nodes. Those nodes are the anchor nodes that send the beacons with position information and the regular nodes with the unidentified position. In addition regards that normal nodes find out their locations using a beacon signal from the anchor. Nevertheless, the beacon signal sent by the anchor node includes anchor coordinates along with the angle of the directional antenna, as well as anchor communication distance. Therefore, Figure 16 shows the average localization error of the hybrid proposed algorithm. The results show that the localization error is suitable concerning the high detector nodes of these two algorithms.

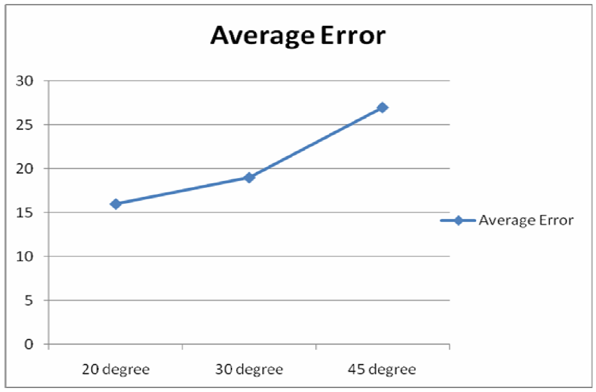

Figure 16: Localization Error in Hybrid Proposed Algorithm

5. Conclusion

Different range-free localization algorithms have been investigated along with increasing the number of beacon nodes, Locators, and static nodes. The simulation results have been obtained by using Wireless Sensor Network Simulator. First, the effect of beacon nodes on range-free localization algorithms is evaluated. The results show that ADLA has the best detection nodes with medium localization error. Moreover, the paper evaluates the effect of locators on algorithm efficiency. The results show that the number of detected nodes in Centroid increased sharply with the increased number of locators. The ADLA has the second-best detection nodes with a supervisor average error than Centroid. Based on the evaluated results this paper proposed a Hybrid of those two algorithms. The proposed algorithms give a better localization error compared to the error of individual ones.

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