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Enhancing Localization Accuracy and Coverage of Centroid Localization Algorithm using NS-2

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Abstract: Localization gets more interest because it is very important for many applications of a wireless sensor networks (WSNs). This paper presents three contributions according to centroid localization algorithm (CLA). The first one is improving the localization accuracy of sensor nodes using the nearest three anchors technique; this proposed algorithm is called enhanced centroid localization algorithm (ECLA). The second contribution which is called centroid localization algorithm using reference nodes (CLAR), aims to increase the percentage of localized sensor nodes (i.e. Coverage) by using reference nodes (localized sensor nodes) broadcasting their estimated position to all unknown sensor nodes (i.e. non-localized nodes). But from simulation results CLAR has higher localization error than CLA, so that the objective is to have low localization error and high coverage which is done by applying the nearest three anchors and/or reference nodes. The final proposed algorithm is called enhanced centroid localization algorithm using reference nodes (ECLAR). The work done in this paper is based on NS-2 simulation by applying different scenarios then measuring the performance of the proposed algorithms. Simulation results show that enhanced centroid localization algorithm using reference nodes (ECLAR) has a better performance (lower localization error and higher percentage of localized sensor nodes) than the conventional centroid localization algorithm (CLA).

Keywords: Centroid, Localization, NS-2, WSNs.

I. INTRODUCTION

Wireless sensor networks (WSNs) has become commonplace in recent years having different fields, ranging from accurate agriculture to environmental monitoring in difficult areas, also from medicine and industries to security, surveillance and home automation[1-4]. Location of sensor nodes is essential in most of the WSNs applications, because the data collected by sensor nodes is meaningless if the localization information is unaware. Localization is being used to identify the location at which sensor readings originate, so that it must be clear so that we can get the position when particular event happened and track it. Due to the limitation of cost and power, manual deployment and installation of GPS devices for all sensor nodes are not the best solutions. Therefore, some mechanisms and algorithms called localization algorithms must be adopted for self-position of wireless sensor network [5].

Localization algorithms for WSNs can be divided into two categories: (i) range-based and (ii) range-free algorithms. Range-based algorithms [6, 7] depend on absolute point-to-point distance or angle information to identify the locations of neighbouring nodes. Range-free algorithms [8, 9] don't take into account the distance or angle information. Algorithms in range-free localization are being pursued as a cost-effective alternative to more expensive range-based approaches, because of the hardware limitations of WSNs devices. Due to the distinct characteristics of these two categories, the range-free localization schemes can be divided into: anchor-based schemes (which assume the presence of sensor nodes in the network that have knowledge about their location) and anchor-free schemes, which require no special sensor nodes for localization [10].
Bulusu and Heidemann [11] have proposed the centroid localization algorithm (CLA), which is a range-free localization algorithm. The algorithm implementation contains three steps. First, all anchor nodes send their locations (x_i, y_i) to all sensor nodes within their transmission range. Each unknown node listens for a fixed time period t and collects all the reply packets it receives from various anchor nodes. Second, all unknown sensor nodes calculate their own locations by a centroid determination from all n locations of the anchors in range according to the following formula:

$$(x_{est}, y_{est}) = \left(\frac{x_1 + x_2 + \cdots + x_n}{n}, \frac{y_1 + y_2 + \cdots + y_n}{n}\right) \quad (1)$$

The centroid localization algorithm (CLA) is simple but the localization error is high due to the centroid formula and the percentage of localized sensor nodes is considered low. Hence, this paper focus on enhancing the localization accuracy of the conventional centroid algorithm by choosing the nearest three anchors to unknown sensor node. Also

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enhancing the coverage of the conventional centroid algorithm by making the reference nodes (localized nodes) sends a localization reply signals to unknown nodes. Simulation results show that enhanced centroid localization algorithm (ECLA) has a better performance than conventional centroid localization algorithm (CLA).

The rest of this paper is organized as follows: section II contains related work. Section III describes the details of the proposed algorithms and their derivation. In section IV, simulation results are reported and a comparative study of the localization performance is conducted. Section V concludes this paper.

II. RELATED WORK

The work presented in [12] proposes Weighted Centroid Localization (WCL), which provides a fast and easy algorithm to locate devices in wireless sensor networks. Authors improve the calculated position of centroid localization algorithm based on real implementations. The proposed algorithm uses weights to attract the estimated position to close reference points provided that coarse distances are available. To estimate the distance from a node to reference points, Link Quality Indication (LQI) is used as a quality indicator of a received packet for Zigbee devices. The disadvantages of this work are as follows: the positioning algorithm does not yet provide the desired results very exactly also real implementation of WCL is based on a small area and a few number of nodes (one unknown and four beacon nodes only).

Authors in [13] propose a new localization algorithm which needs no additional hardware support and can be implemented in a distributed way. Also it can be effectively used in three-dimensional (3D) wireless sensor networks. The proposed method can improve the location accuracy with relatively low communication traffic. Simulation results show that the proposed algorithm has a better performance than conventional centroid algorithm. It can be stated that while the proposed algorithm improves the location accuracy, it requires high computational complexity due to the complex mathematical models used.
In [14], the accuracy of indoor localization measurement based on a wireless sensor network is analysed using position estimation procedure. This procedure is based on the received-signal-strength measurements collected in a real indoor environment. Authors considered two different classes of low-computational-effort algorithms based on the centroid concept. Hence, different sources of measurement uncertainty are analysed by means of theoretical simulations and experimental results.

Yu HU and Weizhao YAO [15] proposed a new localization algorithm named weighted centroid localization algorithm using linear regression. The new algorithm is based on linear regression mathematical model; hence it improved centroid localization algorithm by using weight, calibrating nodes' position. After that it corrected the position through making certain parameters. Authors compared the proposed algorithm with the centroid localization algorithm using MATLAB. Simulation results showed that new algorithm's average localization error dropped by over 60% when anchor node's density was over 5%.
According to [16], authors proposed an improved centroid localization algorithm (ICLA) which is based on APIT and the quality of perpendicular bisector. Simulation results showed that ICLA can be an alternate solution for the node self-localization problem in large-scale wireless sensor networks because it obtains a better localization result in random topology networks without any additional hardware. But in this work, a number of practical factors may affect efficiency, accuracy, and flexibility of localization approaches need to be considered.

The work presented in [17], proposed an ellipse centroid localization algorithm. The main idea of this algorithm is the precision control factor which capable of controlling the algorithm's location accuracy. In order to strengthen anchor density's dynamic characteristic, node is extended as anchor. This algorithm makes use of ellipse's characteristic to estimate the unknown node's coordinate. Simulation results show that ellipse centroid localization algorithm has a better performance than the centroid algorithm and the weighted centroid precision algorithm.

Authors in [18] proposed a weight-compensated weighted centroid localization algorithm based on RSSI for an outdoor environment. The simulation results show that the proposed algorithm is better than AMWCL-RSSI (Anchor_optimized Modified Weighted Centroid Localization based on RSSI) and WCL (Weighted Centroid Localization) in terms of the localization accuracy. The proposed algorithm has the advantage of lower complexity, little prior information and lower power consumption. This work also done based on real implementations which showed that WCWCL-RSSI (Weight-Compensated Weighted Centroid Localization Based on RSSI) is better than WCL in terms of the localization accuracy.

As stated above, much more work has been done for improving the accuracy of centroid localization algorithm. But none of them improved the accuracy of centroid localization algorithm based on NS-2 [19] simulations. Also, they

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don't pay attention for increasing the percentage of localized sensor nodes; which is considered an important factor for many applications of wireless sensor networks. So that the work proposed in this paper aims to enhance the localization accuracy of centroid localization algorithm as well as increasing the percentage of localized sensor nodes based on NS-2 simulations.

III. THE PROPOSED ALGORITHMS

This section is divided into three sub-sections; the first one explains how to enhance the localization accuracy of centroid localization algorithm (CLA) by presenting enhanced centroid localization algorithm (ECLA). The second sub-section presents CLAR algorithm which aims to increase the percentage of localized sensor nodes for centroid localization algorithm (CLA). The third sub-section illustrates the ECLAR algorithm which aims to get high localization accuracy and high coverage; which is done by using the nearest three anchors mechanism and also using reference nodes.

A. Enhanced Centroid Localization Algorithm (ECLA)

A wireless sensor network with a total number of **n** nodes consists of **A** Anchor nodes, **U** unknown nodes and **R** Reference nodes. Anchors are equipped with more efficient hardware and localization system (GPS), whereby they are able to determine their own position which is assumed to be exact. Unknown nodes consists of minimal hardware and initially don't know their own position. Reference nodes are considered localized sensor nodes, which are willing to help other nodes to estimate their position. These three set of nodes can be defined as follows:
$A = \{a_j, \text{ where } j \in \{1, 2, \ldots, C(A)\}\}$
$U = \{u_i, \text{ where } i \in \{1, 2, \ldots, C(U)\}\}$
$R = \{r_j, \text{ where } j \in \{1, 2, \ldots, C(R)\}\}$

Where C( ) is the cardinality of a specific set. It is assumed that the unknown nodes are range sensor nodes producing distance measurements $\mathbf{d_{i,j}}$ (between unknown node $\mathbf{u_i}$ and anchor node $\mathbf{a_j}$) by measuring the RSS of radio signals.

In centroid localization algorithm (CLA), all unknown sensor nodes calculate their own locations by a centroid determination from all **k** locations of the anchors in range according to equation (1). But it is desirable to select those anchors (i.e. subset of anchors) that could contribute more to accuracy, rather than using all the available anchors. Hence, enhanced centroid localization algorithm (ECLA) aims to select the proper subset of anchors. The goal is to use a low number of anchors to achieve high accuracy. Using a simple technique, such as selecting the nearest three anchors, would make it possible to achieve the proper accuracy. The following steps summarize the process of enhanced centroid localization algorithm (ECLA):

PROPOSED ALGORITHM 1: ENHANCED CENTROID LOCALIZATION ALGORITHM (ECLA)
1) All anchors send their position $a_j(x, y)$ to all sensor nodes within their transmission range. 2) Unknown node u_i computes the distance $d_{i,j}$ to each anchor node in range. 3) Unknown node u_i selects the nearest three anchors; e.g. $a_l(x_l, y_l)$, $a_m(x_m, y_m)$ and $a_n(x_n, y_n)$ by choosing the anchors which have the lowest distances to it. Hence: $\{d_{i,l}, d_{i,m}, d_{i,n}\} \subseteq \{Min(d_{i,j})\}$ where $d_{i,l}$, $d_{i,m}$ and $d_{i,n}$ are distances between unknown node u_i and anchors a_l, a_m and a_n respectively. 4) Unknown node u_i calculates its own position according to the following formula: $P_{esti}(x_{esti}, y_{esti}) = \frac{a_l(x_l, y_l) + a_m(x_m, y_m) + a_n(x_n, y_n)}{3}$ (2) 5) According to NS-2 simulation, average localization error can be computed as follows: $ALE_i = \frac{1}{n_{est}} \sum_{i=1}^{n_{est}} \sqrt{(x_i - x_{esti})^2 + (y_i - y_{esti})^2}$ (3) Where n_{est} represents the number of unknown nodes that have been localized; and (x_i, y_i), (x_{esti}, y_{esti}) represents actual and estimated position of unknown node respectively.

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As stated above unknown node computes the distance to each anchor node in range. Measuring the received signal strength (RSS) of the incoming radio signal is considered one possibility to acquire a distance. The derivation of measuring the distance is illustrated in the following. The idea behind RSS is that the configured transmission power (P_{TX}) at the sending end directly affects the receiving power (P_{RX}) at the receiving end. The detected signal strength decreases quadratically with the distance to sender. According to Friis' free space transmission equation [20], the detected signal strength can be expressed as follows:

$$P_{RX} = P_{TX} . G_{TX} . G_{RX} \left(\frac{\lambda}{4\pi d}\right)^2 \quad (4)$$

Where G_{TX} is the gain of transmitter (anchor node) antenna. G_{RX} is the gain of receiver (unknown node) antenna. λ is the wave length. d is the distance between the anchor node and the unknown node. In embedded devices, the received signal strength (RSS) is converted to a received signal strength indicator (RSSI) which is defined as ratio of the received power (P_{RX}) to the reference power (P_{Ref}). Typically, the reference power represents an absolute value of P_{Ref} = 1mW. RSSI can be expressed as:

$$RSSI = 10. log\left(\frac{P_{RX}}{P_{Ref}}\right) \quad [dBm] \quad (5)$$

According to NS-2 simulation, d can be calculated as follows:

$$d = \lambda . \sqrt{\frac{P_{TX} . G_{TX} . G_{RX}}{4\pi . P_{RX}}} \quad (6)$$

But the ideal distribution of P_{RX} is not applicable in practical scenarios; because of the interference of radio signal with a lot of influencing effects e.g. diffraction at edges, polarization of electromagnetic fields, refraction by media with different propagation velocities finally reflections on objects. These effects degrade the quality of the determined RSSI significantly. Thus in NS-2, simulating the degradation for RSSI by adding noise to the calculated distance as expressed in the following formula:

$$d_{noisy} = d + N_\sigma \quad (7)$$

Where d is the ideal calculated distance without any noise or error, N_σ zero-mean Gaussian random variable representing the noise with standard deviation σ. The standard deviation affects the level of noise contained in the transmitted signal. Hence, when increasing standard deviation σ value, the level of noise increases and vice versa.

B. Centroid Localization Algorithm using Reference nodes (CLAR)

In anchor-based localization system, special nodes called anchors are required for location discovery. Anchors know their location through a GPS receiver or manual configuration. The rest of the nodes that have no knowledge about their location are called unknowns. If the node u_i can estimate its position, it could act as a reference r_j for other nodes. Since only the local information is considered, the node u_i will consider only the reachable references within its range, i.e.

$$R_j = \{r_j, \text{where } d_{i,j} \le r_{tx}\}.$$

Where r_{tx} is the transmission range of the reference node. After a period of time this set (R_j) will consist of a large number of references. Using all of them could increase the number of localized sensor nodes. Hence, centroid localization algorithm (CLA) can be modified so as to increase the percentage of localized sensor nodes (coverage). The modification is done based on broadcasting messages from reference nodes to unknown nodes. The following algorithm illustrates the steps required to increase the percentage of localized sensor nodes.

PROPOSED ALGORITHM 2: CENTROID LOCALIZATION ALGORITHM USING REFERENCE NODES (CLAR)
1) Initially, anchor nodes A_j broadcast a messages containing their ID and position as follows: A_j: { a_j + (x_j, y_j) }   2) Unknown nodes U_i receive broadcast messages according to the following condition: $U_i = \{u_i, \text{where } d_{i,j} \le r_{tx}\}$ where r_{tx} is the transmission range of source nodes.   3) Unknown node u_i estimates its own position as expressed below:

$$(x_{est}, y_{est}) = \left(\frac{x_1 + x_2 + \cdots + x_n}{n}, \frac{y_1 + y_2 + \cdots + y_n}{n}\right) \quad (8)$$

where n, number of source nodes broadcasting messages.

4) Each localized sensor node u_i becomes a reference node R_i, according to the following condition:

$$R_i = \{u_i, \text{ where } u_i \text{ has estimated its position}\}$$

5) After a period of time, anchor nodes A_j and reference nodes R_i broadcast a messages containing their ID and position as follows:

$$A_j: \{ a_j + (x_j, y_j) \}, \quad R_i: \{ r_i + (x_i, y_i) \}$$

6) Return to step 2.

C. Enhanced Centroid Localization Algorithm using Reference nodes (ECLAR)

Localization process is based on physical measurements, which may be significantly inaccurate owing to several types of errors. Therefore it is crucial to consider error sources and error propagation in order to design an accurate localization algorithm. In fact, these sources can cause mainly three types of error, Firstly, computation error e_i^c comes from the node that performs the estimation; secondly, location error e_j^l arises from the references used; and thirdly, distance-measurement error $e^d_{i,j}$ occurs between the node and the references used. According to CLAR algorithm, when the node u_i estimates its position using R_i set of references, the resulting total error e^t_i, can be expressed as a function of these three errors as follows:

$$e^t_i = f(e_i^c + e_j^l + e^d_{i,j}), \text{ where } j \in R_i$$

This total error represents the localization error of node u_i ($e^l_i = e^t_i$). Node u_i could become a reference r_i for other neighboring nodes. Its error will affect not only these neighbors but could also affect those nodes using these neighbors as references. Although this algorithm has high coverage, it gives low localization accuracy. So that designing an efficient localization algorithm for WSNs does not encourage using all of the available references.

The final proposed algorithm is called enhanced centroid localization algorithm using reference nodes (ECLAR), aims to select the nearest reference nodes contributing to the localization process. This approach is based on choosing the nearest references as a subset to estimate a node's position, assuming that the estimation error would be higher for distant references than for near ones. This approach could improve the accuracy of location estimation in WSNs. The steps of this algorithm can be listed as follows:

PROPOSED ALGORITHM 3: ENHANCED CENTROID LOCALIZATION ALGORITHM USING REFERENCE NODES (ECLAR)

1) Initially, repeat steps 1, 2, 3, 4 and 5 of CLAR algorithm.

2) Unknown node u_i computes the distance $d_{i,j}$ to each neighbor (anchor and/or reference) nodes in range.

3) Unknown node u_i selects the nearest three neighbor nodes; e.g. $h_l(x_l, y_l)$, $h_m(x_m, y_m)$ and $h_n(x_n, y_n)$ by choosing the anchors/references which have the lowest distances to it. Hence:

$$\{d_{i,l}, d_{i,m}, d_{i,n}\} \subseteq \{\text{Min}(d_{i,j})\}$$

where $d_{i,l}$, $d_{i,m}$ and $d_{i,n}$ are distances between unknown node u_i and neighbors h_l, h_m and h_n respectively.

4) Unknown node u_i calculates its own position as expressed below:

$$P_{esti}(x_{esti}, y_{esti}) = \frac{h_l(x_l,y_l) + h_m(x_m,y_m) + h_n(x_n,y_n)}{3} \quad (9)$$

5) According to NS-2 simulation, average localization error can be calculated as expressed in equation (3).

The difficulties of setting up a WSN with real implementation and the infeasibility of analysis make simulation an essential tool to study WSNs. Simulation is broadly used in system modeling for WSNs applications including engineering research, business analysis, manufacturing planning and biological science research. The following section provides a detailed description of simulation results based on NS-2 using different scenarios then making a comparative study of the proposed algorithms.

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IV. PERFORMANCE EVALUATION

This section evaluates the proposed algorithms, looking at the effects of nodes' deployment, nodes' density and network size on the localization error and coverage. It will examine the impact of increasing the distance-measurement error on the accuracy of the ECLA algorithm. Also this section will compare the performance of the CLAR, ECLA and ECLAR algorithms against the conventional centroid localization algorithm CLA. Also illustrating the pros and cons for each algorithm and provides solutions to overcome these drawbacks.

A. Performance Metrics

The performance of each proposed algorithm was evaluated based on two metrics: localization error (PLE_i) and Coverage.

According to the first metric, it can be calculated as a percentage of R_{tx} as expressed in the following formula:

$$PLE_i = \frac{ALE_i}{R_{tx}} * 100 \quad (\%R_{tx}) \qquad (10)$$

Where ALE_i is the average localization error for sensor node i computed from equation (3) and R_{tx} is the transmission range for sensor node. According to the second metric, Coverage can be defined as the percentage for the number of localized sensor nodes as expressed in the following equation:

$$Coverage = \frac{C(L)}{C(L) + C(U)} * 100 \quad (\%) \qquad (11)$$

Where L is the set of localized sensor nodes, C(L) is the number (cardinality) of localized sensor nodes and C(U) is the cardinality of unknown nodes.

B. Simulation Model

NS-2 has several modules and tools that researchers can use to implement localization algorithms. The researchers can modify the existing modules, or create new ones from scratch. Therefore, NS-2 simulator has been extended for implementing and evaluating the proposed localization algorithms. Simulation model is based on two forms of nodes deployment, the first one is dividing the deployment field into several regions with area 50×50 m^2 and each region contains the same number of unknown sensors and anchors without ignoring the randomness of node distribution. The second form is random deployment; where unknown sensors and anchors are deployed randomly irrespective of the area they found.

All nodes had a limited transmission range (R_{tx}) of 50 m. At each experiment the simulation was run 5 times; the duration of each run was 200 sec (the total duration was 1000 sec), and at each run nodes were redistributed randomly in different places (using a different seed value).

By varying the size of deployment area and number of sensor nodes, there are four scenarios are used to evaluate the proposed algorithms. The characteristics of all scenarios are shown in table I and simulation parameters are shown in table II.

TABLE I CHARACTERISTICS OF SCENARIOS

Characteristics	Scenario			
	I	II	III	IV
Deployment Area (m^2)	100 x 100	200 x 200	100 x 100	200 x 200
Number of regions	4	16	---	---
Number of unknown nodes	100	208	100	200
Number of anchors per region	4, 5, 6, 7 and 8	2, 3, 4, 5 and 6	---	---
Total number of anchors	16, 20, 24, 28 and 32	32, 48, 64, 80 and 96	5, 10, 15, 20, 25, 30 and 35	10, 20, 30, 40, 50, 60, 70, 80 and 90
Localization Error	√	√	√	√
Coverage	x	x	√	√

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TABLE II SIMULATION PARAMETERS

Parameter	Value
Channel type	Channel/ Wireless Channel
Radio-propagation model	Propagation/Free Space
Network interface type	Phy/WirelessPhy
MAC type	Mac/802.11
Interface queue (IFQ) type	Queue/DropTail/PriQueue
Link layer type	LL
Antenna model	Antenna/OmniAntenna
Max packets in IFQ	50
Routing protocol	AODV
Transmitting power in watts	0.281838
Receiving power in watts	0.281838
Initial energy in Joules	20.0
Receive sensitivity threshold	7.69113e-08 watt
Carrier sense threshold	5.3352e-06 watt
Transmitter antenna gain G_{tx}	1
Receiver antenna gain G_{RX}	1

C. Results and Comparisons

This sub-section will evaluate the performance of the proposed algorithms using the scenarios described in table I. Several experiments were performed to evaluate the performance of the ECLA, CLAR and ECLAR algorithm compared with CLA algorithm. By using NAM as a visualization tool there are three colors used for each node type; i.e. unknown nodes have a blue color; anchor nodes have a green color and reference nodes have a red color. There are four scenarios used to evaluate the performance of the proposed algorithms based on two metrics: localization error and coverage. These scenarios are listed in the following sub-sections.

1. Scenario I:

In this scenario, 100 m × 100 m deployment area which is divided into four sub-areas (regions) each is 50 m × 50 m. There are 100 unknown nodes distributed over the whole area and there are approximately 25 unknown nodes in each region. There are five different values for the number of anchors per region as follows 4, 5, 6, 7, and 8 which are distributed randomly in each one. So that, total number of anchors is 16, 20, 24, 28 and 32 anchor node. The topology of first scenario is shown in Fig. 1.

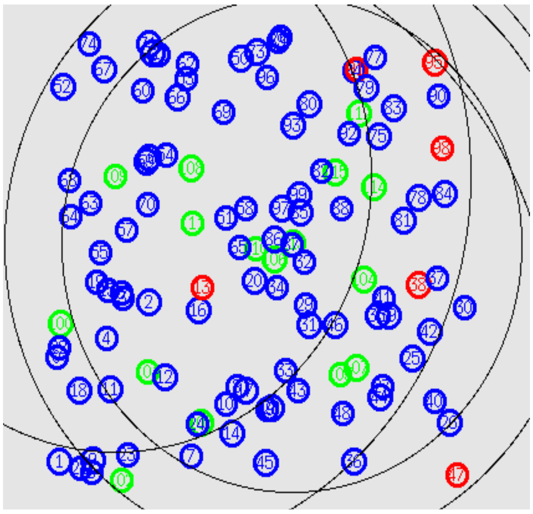

Fig. 1. First Scenario Topology

The purpose of this scenario is to evaluate the performance of enhanced centroid localization algorithm (ECLA) against the conventional centroid localization algorithm (CLA) based on the first metric (localization error). As shown in Fig. 2, the localization error decreases gradually for both algorithms because the number of anchor nodes increase. As stated before, the standard deviation σ is used to simulate the noise level contained in the transmitted signal.

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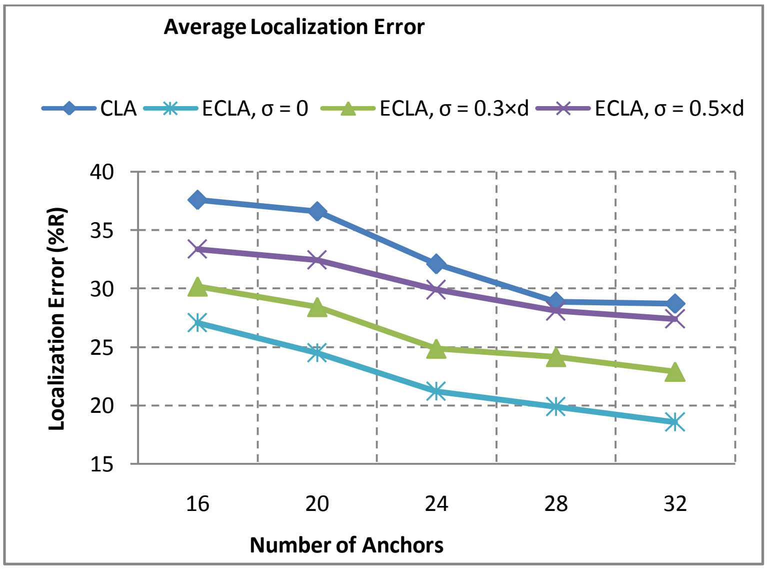

Fig. 2. Average Localization Error of Scenario I

In this experiment, the standard deviation takes three values as a ratio of the distance d between unknown node and anchor node (i.e. σ = 0×d, 0.3×d and 0.5×d). From Fig. 2, the localization error of ECLA increase as the standard deviation σ increases. For example when taking high value for standard deviation e.g. σ = 0.5×d, the localization error of ECLA still lower than CLA algorithm. Finally, ECLA algorithm has a lower localization error than CLA.

2. Scenario II:

In this scenario, the deployment area is 200 m × 200 m which is divided into 16 sub-areas (regions) each has 50 m × 50 m area. There are 208 unknown nodes distributed over the whole area and there are approximately 13 unknown nodes in each region. There are five different values for the number of anchors per region as follows 2, 3, 4, 5 and 6 which are distributed randomly in each one. So that, different values of total number of anchor nodes are 32, 48, 64, 80 and 96 anchor node. The topology of second scenario is shown in Fig. 3.

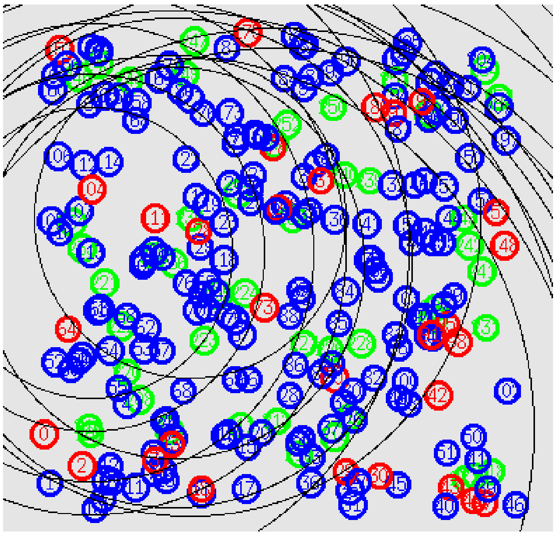

Fig. 3. Second Scenario Topology

Also this scenario is used to evaluate the performance of ECLA against CLA algorithm based on the first metric (localization error) but for lager area than the first scenario. From Fig. 4, the localization error for both algorithms decreases gradually as the number of anchor nodes increase. In this experiment, the standard deviation σ takes three values 0×d, 0.06×d and 0.1×d. From Fig. 4, the localization error of ECLA algorithm increase as the standard deviation σ value increases. But ECLA algorithm still has a lower localization error than CLA algorithm even if the value of standard deviation is increased (e.g. σ = 0.1×d). Finally, ECLA algorithm has a lower localization error than CLA algorithm for larger deployment area.

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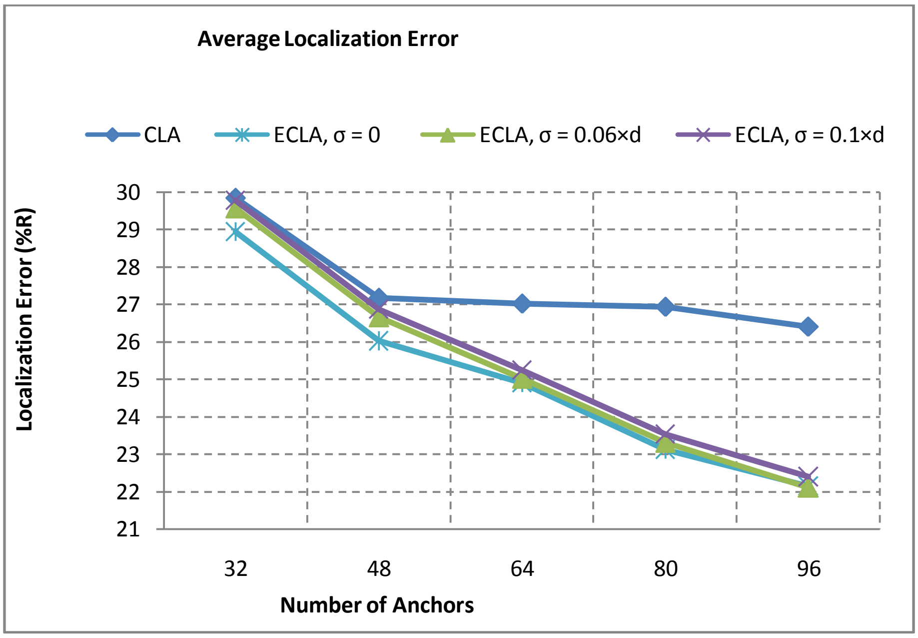

Fig. 4. Average Localization Error of Scenario II

3. Scenario III:

This scenario aims is to evaluate the performance of CLA, CLAR and ECLAR algorithms based on two performance metrics: coverage and localization error. In this scenario, the deployment area is 100 m × 100 m which is not divided into regions as before so as to deploy sensor and anchor nodes randomly irrespective of their regions. The reason for deploying nodes randomly over the whole area is to measure the capability of the proposed algorithms to give high coverage under the worst cases. There are 100 unknown nodes distributed randomly over the deployment field. There are seven different values for the number of anchors distributed randomly as follows 5, 10, 15, 20, 25, 30 and 35. At each value, coverage and localization error can be measured with different seed values. The topology of this scenario is shown in Fig. 5.

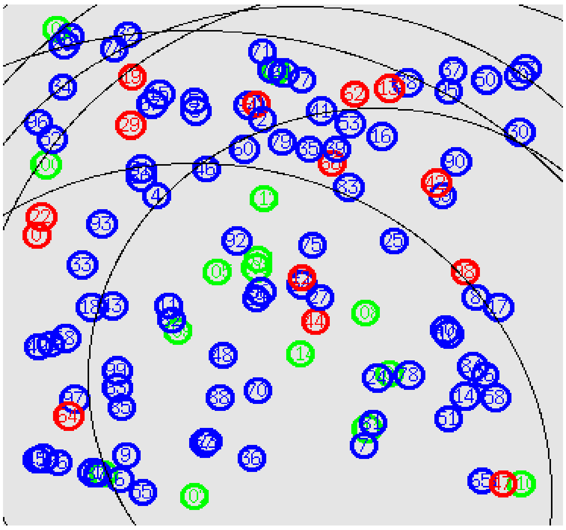
Fig.5. Third Scenario Topology

As shown in Fig. 6, the percentage of localized sensor nodes (coverage) for CLA algorithm increases gradually as the number of deployed anchor nodes increase. CLA algorithm begins with low coverage (44%) and increases to 100% but at the expense of large number of anchor nodes. Hence, CLAR algorithm is proposed to give high coverage but with a fewer number of anchor nodes. From Fig. 6, CLAR and ECLAR algorithms have 100% coverage at low number of anchor nodes. According to Fig. 7, CLAR algorithm has a higher localization error than CLA algorithm, because it relies on reference nodes to estimate position. Hence, ECLAR algorithm is proposed to overcome the limitations of CLAR by having high coverage at low number of anchor nodes and at the same time enhancing localization accuracy.

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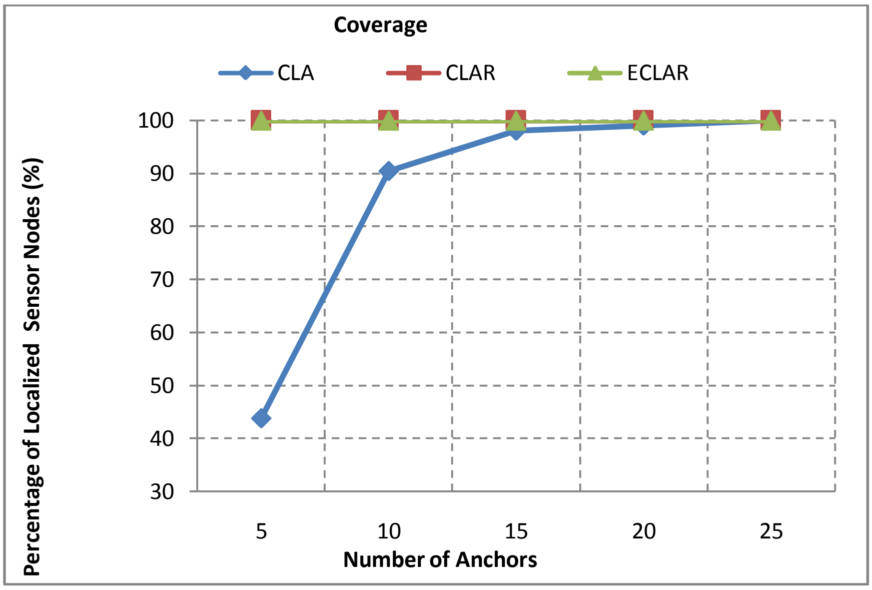

Fig. 6. Coverage of Scenario III

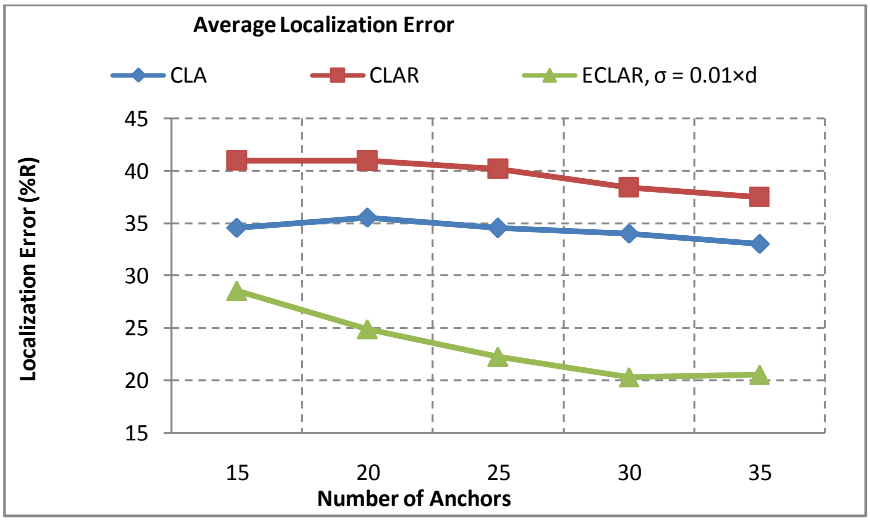

Fig. 7. Average Localization Error of Scenario III

4. Scenario IV:

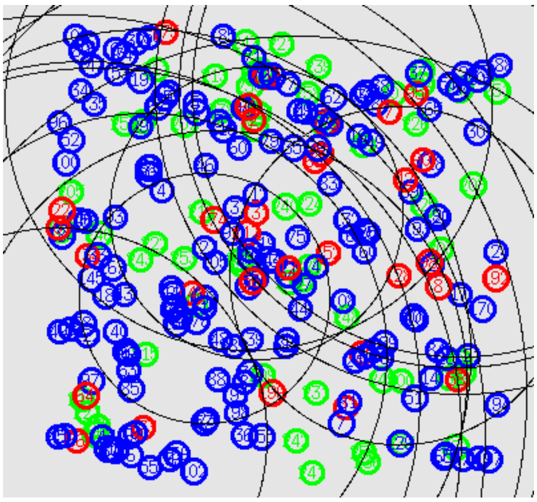

Fig. 8. Fourth Scenario Topology

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This experiment aims to use large scale WSN to evaluate the performance of CLA, CLAR and ECLAR algorithms according to coverage and localization error.

In this scenario, the deployment area is 200 m × 200 m and the deployment of sensor and anchor nodes is done randomly irrespective of their regions as stated in scenario III. There are 200 unknown nodes distributed randomly over the deployment field. Coverage and average localization error can be measured with different seed values at different number of anchor nodes as follows: 10, 20, 30, 40, 50, 60, 70, 80 and 90. The topology of this scenario is shown in Fig. 8.

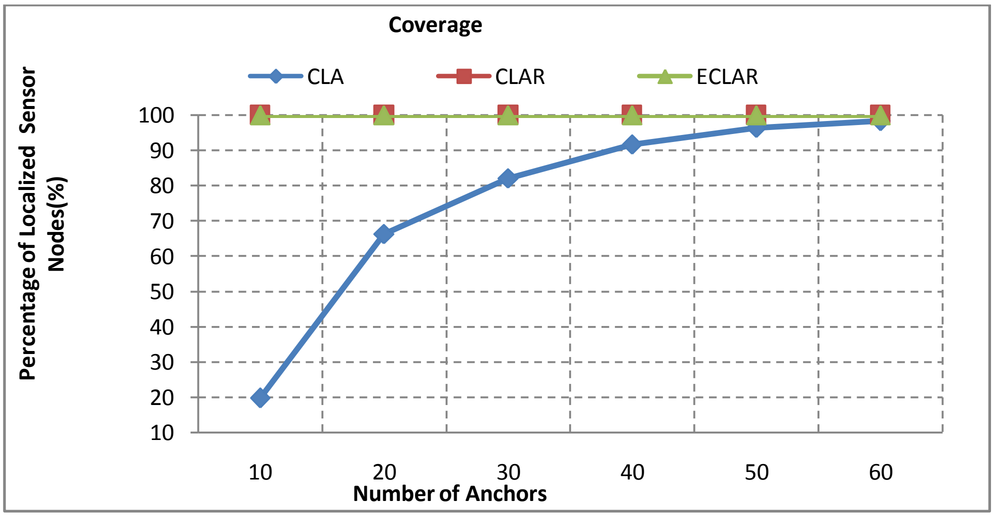

Fig. 9. Coverage of Scenario IV

As shown in Fig. 9, coverage of CLA algorithm increases gradually as the number of anchor nodes increase. At high number of anchors (50 nodes), coverage reach 98% approximately. Thus, CLA algorithm needs high number of anchor nodes to give high coverage. CLAR algorithm has higher coverage at low number of anchor nodes but it has higher localization error (low accuracy) than CLA algorithm, see Fig. 10. Hence, ECLAR algorithm is proposed to overcome this problem by having the lower localization error as shown in Fig. 10. Also it has high coverage at low number of anchor nodes as illustrated in Fig. 9.

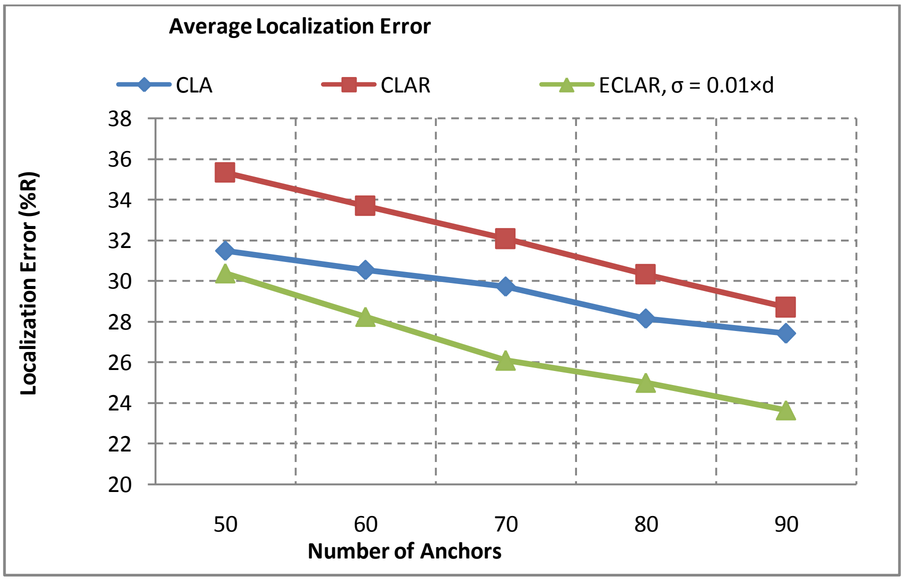

Fig. 10. Average Localization Error of Scenario IV

5. Comparison of the Proposed Algorithms:

Each of these proposed algorithms has advantages and disadvantages and it is not possible to consider one of them as the best localization algorithm for every application, scenario or network. The selection of one of these algorithms to be

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implemented in WSNs is a little more complicated because of resource limitations. When deciding which localization algorithm will be used, several issues should be considered, such as available resources, security level, computational cost, time of convergence and accuracy level.

A comparative summary is provided in Table III. This table highlights some of the advantages and disadvantages of the proposed algorithms. The last two fields of this table (targets and limitations) could be used as a guideline to help the designer to select an applicable approach that would be more suitable for his specific system requirements. Targets represent the issues that can be achieved using the corresponding algorithm, while limitations indicate the issues that cannot be achieved (or not completely fulfilled).

TABLE III COMPARISON OF THE PROPOSED ALGORITHMS

	ECLA	**CLAR**	**ECLAR**
Advantages	• Accuracy	• High coverage • Few anchors	• Accuracy • High coverage • Few anchors
Disadvantages	• Low Coverage	• High localization error	• Vulnerable to attacks
Targets	• Localization error	• Coverage	• Localization error • Coverage
Limitations	• Coverage	• Localization error	• Security

V. CONCLUSION AND RECOMMENDATION

Centroid localization algorithm (CLA) relies on using a high number of anchors to estimate the position of sensor nodes. On the other hand, it has several drawbacks, especially for resource-constrained WSNs. Using a high number of anchors requires more computations and more memory space and consumes more energy. Therefore, CLA algorithm could be infeasible for resource-constrained WSNs. Furthermore, the availability of a high number of anchors is a critical issue that cannot be guaranteed in WSNs.

Using only a subset of (nearest three) anchors could help to overcome the problems associated with using all the available anchors; this is considered the design issue of ECLA algorithm. Moreover, following this technique (i.e., using a subset of anchors) will help to achieve several design objectives, such as accuracy, robustness, simplicity and energy efficiency. However, selecting a subset of anchors cannot be considered as the last resort, because the coverage of this technique is questionable. So it is a real challenge to achieve several design objectives at once. Hence CLAR algorithm is proposed to fulfill only the coverage design objective, but this affects the accuracy of the proposed algorithm.

An efficient localization algorithm was proposed, it relies on using a low number of reference nodes to achieve an accurate estimation without compromising other design objectives of the algorithm (such as simplicity, robustness and energy efficiency). This algorithm was termed enhanced centroid localization algorithm using reference nodes (ECLAR). This algorithm is based on a selecting the nearest three neighbor (anchor and/or reference) nodes. This algorithm is considered cost-effective because it increases the location accuracy and coverage with a few numbers of anchors. Simulation results confirm that the proposed localization algorithm (ECLAR) allow for reliable and accurate location information to be gathered using a minimum number of neighbors. This decreases the computational burden of gathering and analyzing location data from the high number of neighbors previously believed to be necessary.

ECLAR algorithm is vulnerable to attacks which lower the localization accuracy. It is recommended to have further research on how to make the proposed algorithm more secure against any hostile attack which threats the whole localization process.

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