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Position Estimate Localization Routing for Large Scale Wireless Sensor Networks

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Abstract: Localization is a significant characteristic in Wireless Sensor Networks (WSNs) area, and it has much research concentration between academia and the research community. WSN is designed and implemented using a vast number of tiny, low energy, limited processing capability and low-cost sensors interconnected wirelessly in an ad-hoc manner. The concept of describing physical coordinates, i.e. the location of sensor nodes in WSNs is a major issue in communication systems to assess the point of origin of events under monitoring. The necessity of the positioning accuracy differs for different applications so different approaches for localization are utilized in various applications. WSNs use two different type of localization methods, Range based and Range-free. Range based localization is expensive and used for accurate position estimation in position-critical applications like forest fire detection, reconnaissance etc. whereas Range-free localization is much economic and used for ascertaining approximate position estimation in not-so-position-critical applications like livestock and animal tracking etc. In this paper, an efficient recursive localization method called Position Estimate Localization Routing (PELR) is proposed for range-free localization. It reduces the consumption of energy, the time of execution, and the communication overhead. It enhances overall system performance for large-scale WSNs taking into consideration the trade-off between location accuracy and time cost. The simulation outcomes demonstrate that the recommended system has enhanced performance than the existing ones.

Keywords: Wireless Sensor Networks; Position Estimation; Range Free Localization; PELR

I. INTRODUCTION

An essential issue in designing a sensor network is localization i.e., finding the position of the sensor. The information of Location is utilized to recognize and record activities or to track packets through geometric-aware routing. The standard arrangement of locations is not possible for large-scale networks or networks where sensors may change. Providing every sensor with localization hardware (e.g., GPS) is expensive regarding cost as well as consumption of energy. A more realistic solution to the localization issue is to permit some nodes (known as seeds) to have their location information at all times and allow further nodes to conclude their locations by swapping data with other nodes. Secure localization of unidentified nodes is an additional important investigation subject today [1]. Location-based authentication also needs the location of anonymous nodes [3] [4]. An assaulter can compromise an unknown node or an anchor node to restrict with localization procedure [2]. Furthermore, an attacker can alter, forge or repeat localization data to make the expected locations of unknown nodes incorrect. In such a consequence, it turns out to be essential to offer secure verification data, to perceive the accuracy of information regarding localization [4]. The concentration may be on the security concerns of localization methods parting other features as distance error, communication, and energy costs included in the procedure of localization [4], [5], [6]. In developing sensor network applications, it turns out to be obligatory for localization of the sensor nodes about a global coordinate system to report information that is geographically meaningful. Localization is the process of making every sensor node in the sensor network to be aware of its geographical position [7]. The sensor data turn out to be worthless without carrying out localization. Localization is deliberated as an implicit feature in a sensor network. The easiest way is to assign a GPS to every sensor node. On the other hand, this solution is costly as mostly the sensor nodes are enormous in quantity in a WSN. It too creates the sensor node bulkier [8]. The localization concern is particularly significant where there is

vagueness about the position of assured nodes. If the sensor network is utilized for observing the temperature in a building, it is probable that we can recognize the particular location of every node. In contrast, if the sensor network is utilized for observing the temperature in a distant jungle, nodes may be positioned from an airplane, and the accurate location of most sensors may be unidentified. An efficient localization procedure can then use all the existing data from the nodes to determine all the positions [9].
The self-localization capability is an extremely needed feature of WSNs. In applications of environmental monitoring like bushfire surveillance, water quality monitoring, and precision agriculture, the measurement data are worthless without identifying the position from where the information is attained. Furthermore, estimation of location might permit innumerable applications similar to reconnaissance, inventory management, road traffic monitoring, etc. [10].

In this paper, an efficient recursive localization method called PELR (Position Estimate Localization Routing) is suggested for range-free localization with enhanced performance. It decreases the energy consumption, the time of execution, and the communication overhead. The overall system performance is enhanced for large-scale WSNs and it considers the trade-off between location accuracy and time cost. Simulation outcomes show that the recommended system has improved performance compared to other techniques as discussed in this study.

Our contribution:

- To achieve overall system performance for LSWSNs that deliberates the tradeoff concerning Location accuracy and time cost.
- To achieve better accuracy.
- To reduce energy consumption as well as the cost of the network.
- To achieve low communication overhead.

The rest of this paper is structured as follows: Section 2 examines the literature review. Section 3 briefly discusses the methodology part of the study. Section 4 discusses the proposed methodology, i.e., Position Estimate Localization Routing. Section 5 presents the evaluation results of PELR (Position Estimate Localization Routing) and compares them against CLA (Centroid Localization Algorithm) in the literature. Section 6 concludes the paper.

II. LITERATURE REVIEW

Abu et al., (2018) provided an outline of the information fusion processes utilized by localization procedures to improve and simplify the position computation procedure. Additionally, numerous approaches were analysed, and that can be used by localized information fusion procedures and deliberated the manner in which these methods improved the performance of information fusion and made information fusion to show a prominent part in localization procedures. This study offered a summary of different localized information fusion techniques for discovering the location of the node in WSNs and can be utilized as an initial point for executing current schemes or designing new methods [11].

Kiruthiga et al., (2017) recommended an Adaptive Signal Strength Based Localization Approach (ASSLA) for increasing the accuracy of position by the node update technique. In this method, the stable paths were created through the finding of Bit Error Rate (BER), signal strength in addition to Packet Delivery Ratio (PDR). When the routes are found, then a cluster is designed with the minimal hop count value. The update value of node location was assessed by the revised vector concept and trilateration technique. From the simulation outcomes and study with network simulation tool (NS 2.34), the recommended method ASSLA exceeds current systems regarding delay, location accuracy, overhead, delivery ratio, location detection efficiency [12].

Baroutis et al., (2017) presented a method for maintaining location confidentiality of the Base Station. This technique introduced deceptive transmissions targeting to even the traffic density through the network and create the BS vaguely. The trade-off concerning location privacy as well as the network's performance was highlighted and they showed the manner of the proposed technique which achieved a balance amongst conflicting metrics. The simulation outcomes confirmed that the suggested traffic analysis countermeasure efficiently boosted the location privacy of the BS lacking a noteworthy influence on the performance along with the lifespan of the system [13].

Wu et al., (2017) proposed a distributed algorithm, Triangle Extension (TE), to define the localizable nodes in a network founded on graph rigidity theory. TE utilized an effective method of triangle extension to build a rigid graph to perceive the localizable nodes and desired less information compared to the existing procedures. Then hypothetically studied the effectiveness of TE associated it with that of the current systems. Simulations in addition to experiments also confirmed that TE was appropriate to real-world WSNs. A hopeful way is to incorporate TE through localization procedures [14].

Farooq-i-Azam et al., (2016) proposed an innovative, intelligent localization procedure which utilized variable range beacon signals produced by changing the transmission power of beacon nodes. The method does not employ any further hardware resources for ranging and estimated position with only radio connectivity through passively listening to the beacon signals. The process is distributed, so every sensor node determined its individual location and communication overhead be evaded. As the beacon nodes do not continuously communicate at maximum power and no transmission power was utilized by unknown sensor nodes for localization, the suggested procedure is energy efficient. It too offered control over localization granularity. Simulation outcomes presented that the process provides better accuracy under changing radio conditions [15].

Lv et al., (2018) proposed an enhanced range-free localization structure for mobile WSNs found on enhanced Population Monte Carlo localization (PMCL) technique, associated with hidden terminal couple structure. Initially, resampling by means of importance weights was presented in the PMCL technique to evade sample degeneracy. Then, twofold constraints, limiting the number of random samples in the initialized step and limiting valid observations in the resampling phases are recommended to reduce the iterations number. Then, mixture perspective was presented to preserve the diversity of samples in resampling weighted procedure. Furthermore, performance assessments of PMCL with further SMC-based schemes were also suggested. Simulation outcomes showed that delay of PMCL has the specific advantage to that of new schemes, and accuracy as well as energy consumption was enhanced in some instances of less anchor rate and lower mobile velocity [16].

Authors in [5], [6] and [7] concentrated on issues that affect a localization method and provided a summary of new challenges and metrics to be carried out in the forthcoming investigation. For instance, a localization structure which could reduce the consumption of energy and reduce communication overhead which was likely to be needed if maximizing network lifespan is a significant deployment goal.

Bouhdid et al., (2017) suggested an efficient recursive localization procedure that decreases the consumption of energy and the time of implementation in addition to the communication overhead, yet it raised the accuracy of localization by means of sufficient distribution of reference nodes inside the network [19], [20].

III. METHODOLOGY

Assessing the performance of the localization procedure is significant for investigators, either to authenticate a novel algorithm or contrary to the previous state-of-the-art or choosing a localization procedure that best fit the necessities of the consistent application scenario. Meanwhile, different applications will have different requirements; it is significant for the investigator to choose whatever performance standards or evaluation metrics that the localization procedure are to be associated with further processes that fit different applications requirement. A broader set of evaluation criteria are beneficial for the developers as well as the users of the localization procedures so as to comprehend the application necessities intensely. Specimens of the metrics are localization accuracy, cost, coverage, etc. These criteria replicate the constraints like computational complexity and drawbacks, consumption of power, cost of unit and scalability of the network. Specific evaluation criteria are binary in nature, such as particular procedures either have specific property or they don't possess, e.g., anchor-based or anchor free; self-configuring or not; etc. Binary criteria can be utilized by investigators to restrict the relative assessment of a procedure against others. For instance, one can restrict the comparative evaluation by means of scheming self-configuring and range free localization procedure by directly controlling the number of comparisons against range-based solutions.

Accuracy:
Accuracy is well-defined as how well the position assessed by the localization algorithm equals the known, ground truth locations. A conventional localization algorithm must offer the match as carefully as possible. Though, positional accuracy is not the only over-riding objective of a good localization algorithm. This is mostly application dependent. Dissimilar applications will possess different necessities on the determination of the positional accuracy. The granularity of the required positional accuracy is contingent on the inter-node spacing. If the inter-node spacing is of the order of 100 m, then a positional error of 1 m can be acceptable. But, if the inter-node spacing is of the order of 0.5 m, then 1 m error is hugely intolerable. It is also significant to measure, how well a localization algorithm attains good accuracies without a full set of input data. For instance, some algorithms such as assume measurements from every node to every other node for the localization algorithm to arrive at a stable estimation. This assumption is totally unrealistic given the realities of deployment environments. Assessment should show the manner in which the performance of the algorithm is affected by measurement noise, bias or uncorrelated error in the input data. It must also find the number of sensor nodes that can essentially be localized. Errors in measurement data are important for those algorithms that are designed to work for 2D and take responsibility to work for 3D also. For the reason that in a 3D environment, measurement noise can consequence in flips and reflections of the assessed coordinates of the sensor nodes. The simplest method to compute accuracy is to define the residual error amongst estimated positions and the actual positions for every single sensor node in the network, sum them and average the result. This is recognized as a mean absolute error (E_{mae}) and is well-defined as

$$E_{mae} = \frac{\sum_{I=1}^{n} \sqrt{(x_I - \widetilde{x_I})^2 + (y_I - \widetilde{y_I})^2 + (z_I - \widetilde{z_I})^2}}{n} \quad (1)$$

where (x_I, y_I, z_I) are actual coordinates and $(\widetilde{x_I}, \widetilde{y_I}, \widetilde{z_I})$ are assessed coordinates of the sensor node. The sensor nodes presented in the network are 'n.' The mean average error has the similarity to the root mean square (rms) error, which is defined as

$$E_{rms} = max_{i=1\ldots n}\sqrt{(x_I - \widetilde{x_I})^2 + (y_I - \widetilde{y_I})^2 + (z_I - \widetilde{z_I})^2} \quad (2)$$

It is also important for the accuracy metric to reflect not only the positional error in terms of the distance but also in terms of the network's geometry. If only average node position error is utilized, then there is a huge variance in the accuracy of the relative geometry of the system assessed by the localization algorithm and the relative geometry of the actual network. This problem was addressed by defining the following metric known as Global Energy Ratio (GER).

$$GER = \frac{1}{\frac{n(n-1)}{2}}\sqrt{\sum_{i=1}^{n}\sum_{j=i+1}^{n}\left(\frac{\widehat{d_{IJ}} - d_{ij}}{dij}\right)^2} \quad (3)$$

The distance error between the estimated distance ($\widehat{d_{IJ}}$) and the known distance (d_{ij}) is normalized by the known distance (d_{ij}), making the error a percentage of the known distance. The GER metric doesn't return the rms error and is addressed by describing an accuracy metric that better reflects the rms error known as Global Distance Error (GDE).

$$GDE = \frac{1}{R}\sqrt{\frac{\sum_{i=1}^{n}\sum_{j=i+1}^{n}\left(\frac{\widehat{d_{IJ}} - d_{ij}}{dij}\right)^2}{\frac{n(n-1)}{2}}} \quad (4)$$

where R signifies the average radio range of a sensor node. The GDE computes localization error signified as a fraction of the average distance nodes might interconnect over.

Cost:
Cost is well-defined as the way in which the algorithm is expensive in terms of consumption of power, communication overhead, pre-deployment arrangement, and time considered for confining a sensor node, etc. An algorithm which can minimize numerous cost constraints is probable to be needed if the maximizing lifespan of the network is the primary goal. However, the cost is an essential trade-off against accuracy and is often motivated by practical applications requirement. For example, a procedure may focus on minimizing communication overhead and complex processing to save power, quick convergence, etc., but at the overall accuracy cost.

IV. PROPOSED METHODOLOGY

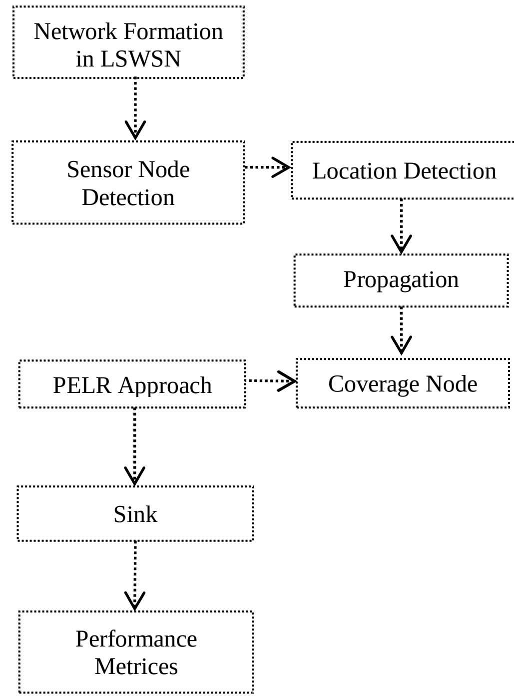

Figure 1. *Proposed Methodology Flowchart*

Figure 1 demonstrates the proposed methodology flowchart. It mainly consists of the stages such as Network Formation in Large-Scale WSN (LSWSN), Sensor Node Detection, Location Detection, Propagation Range Check, Coverage Node Detection, PELR approach, Sink and Performance metrics which are discussed in the next sections.

The approach of PELR is mentioned in following steps:

To determine the routing path, firstly initialize the set of sensor nodes. Let the set of sensor nodes be *nm*. The number of nodes may be $n_1, n_2, n_3, \ldots\ldots n_n$. The locations of the number of sensor nodes with the topology range are found in terms of *x* and *y* coordinates. If a specific node finds a beacon neighbouring node, the inner circle (range) radius and estimate range are found. A radius of the inner circle is calculated by the difference between the outer circle and the range of the signal. Estimate range is estimated by the average of the radii of inner and outer circles. Estimate position is determined only when the neighbouring beacons are greater than the maximum range. This is done by iterative multilateration technique using all neighbouring beacon nodes. Then the exact locations of the nodes within the range along with *x* and *y* coordinates are found. After identifying a route for communication, the next process is the mode of selection. Intra-communication is done when the sensor nodes are within the range of communication. If the sensor nodes are not present within the communication range, then inter-communication is chosen. Inter-communication is done via relay such as in Multi-hop networking. The final step is to calculate the performance metrics of the entire networking system.

PELR (Position Estimate Location Routing) Algorithm:

Begin

Step 1:

Set $nm\ [i]$;
where nm → a set of sensor nodes.
Initialize the sensor nodes as
Set $nm\ [i]$ = {$n_1, n_2, n_3, \ldots\ldots n_n$ };

Step 2:
The following equation is used to find out the location of all the nodes in the coverage area.

$$loc[s] = \sum_{i=0}^{nm} val(\, n_{nx}, n_{ny})$$

where $loc[s]$ is the node's location
nx and ny are the x and y coordinates of specifically chosen number of nodes.

for {set i 0} {i <nm } {incr i }
{
Location [sensor]= Nx [i], Ny [i];
Set val (n_{nx}) = Nx [i];
Set val (n_{ny}) = Ny [i];
disp (n_{nx},n_{ny});
}

Step 3:
while (N [i] == Beacon neighbour nodes)
{
Inner circle radius = Outer circle radius – Range of signal
Estimated range = Average of radii of inner and outer circles
}

Step 4:
if (Number of neighbour beacons ≥ Maximum range)
{
Estimated position = Multilaterate all neighbour beacon nodes
}

Step 5:
The location of the neighbouring nodes is given as

$$loc[n_n(i)] = \sum_{i=0}^{n_n}\sum_{j=0}^{n_n} val(xx_i\,, yy_j)$$

where $loc[n_n(i)]$ is the location of neighbouring nodes and xx_i & yy_j are the x and y coordinates for a set of nodes.

while {set $i < n_n$}
{
for {set $j = 0$} {j<n_n} {incr j }
{
location [n_n (i)] = val (xx_i), val (yy_j)
}
}
incr i;

Step 6:
if (Sensor is within the range)
{
Communication → Intra-communication (Single-hop)
}
elseif (Sensor is out of range)
{
Communication → Inter-communication through relay (Multi-hop)
}

Step7:
Calculate performance metrics of the network.

End

V. RESULTS AND DISCUSSION

This section presents the results and discussion of the study which mainly includes the results obtained for the Network Formation, Sensor Node Detection, Sensor Id, Location Detection, Propagation Range, Position Estimation, Data Communication, Mobility of Nodes, Mobility Location.

The implementation is carried by using *Network Simulator-2 (NS2)* software showing here the screenshots of progress of work using *NAM* followed by the performance graph plots on various parameters using *xgraph* utility.

The simulation parameters considered for the proposed work are as follows:

Table 1. Simulation parameters

Parameter	**Value / Description**
Channel	Wireless Channel
MAC Type	802.11
Propagation Model	Two Ray ground
Number of Nodes	250
Routing Protocol	DSDV

Topography Range	984,995
Antenna	Omnidirectional
Network Domain	Large-Scale Wireless Sensor Network
Simulation Time	50s

Network Formation

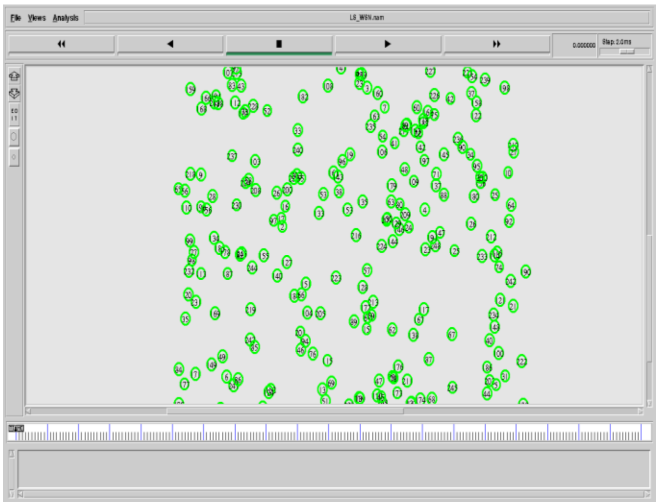

Figure 2. *Network Formation*

Figure 2 represents the process of the proposed methodology which uses the domain of LSWSN for the purpose of network formation. In this Large Scale WSN, Network Formation includes a set of nodes. All nodes are assigned id (like n_1, n_2, n_3, n_4, n_5, n_6, n_7 ...n_{250}). Here network is formed as the structure through a collection of nodes or system.

Sensor Node Detection

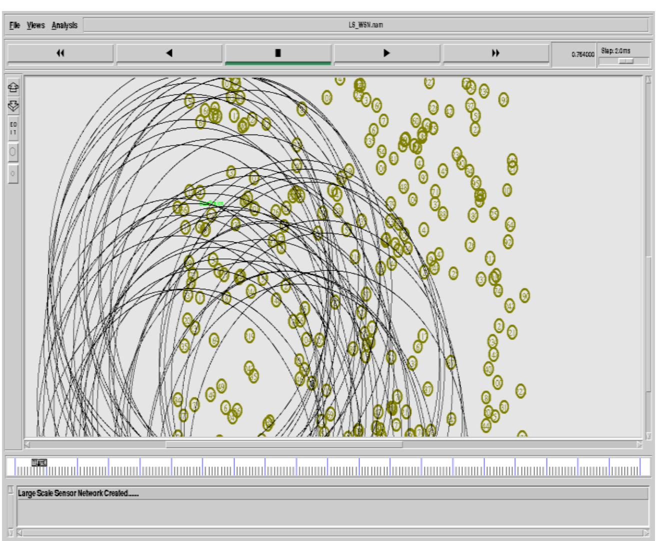

Figure 3. *Sensor Node Detection*

Figure 3 shows the sensor node detection process in which all sensor nodes are positioned in individual locations. This is required to detect each and every sensor node through sensor ID by sensor devices.

Sensor Id

Figure 4. *Sensor Id*

Figure 4 showing all the sensor IDs being displayed post the sensor node detection process during implementation.

Location detection:

In this stage, we detect locations of all sensor nodes and discover the path through Position Estimate Localization Routing (PELR) process for data transmission.

Propagation Range

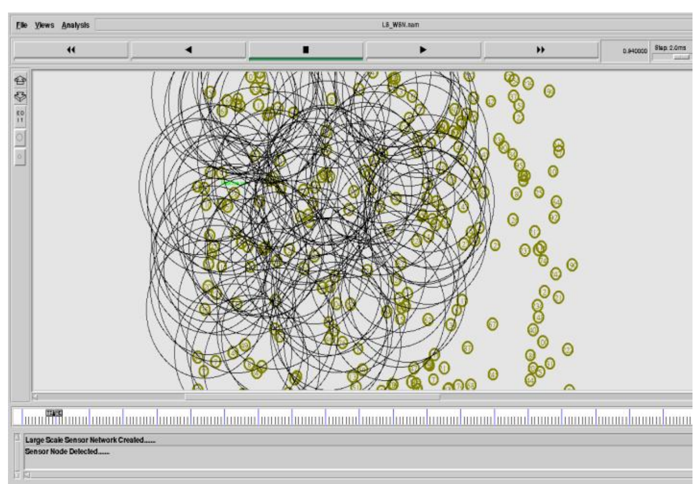

Figure 5. *Propagation Range*

Figure 5 provides the information about the propagation range. There is a necessity to determine the propagation range before the transmission. Let us consider, 'A' is a sending node and 'C' is a destination node. Then we need to check whether the propagation range is within the communication range or not.

Position Estimation

In this position estimation phase, all nodes are initially placed or positioned on its locations, then during the transmission time, those particular nodes will independently relocate from their current location to their target location. In this case, there is a need to predict all *'x'* and *'y'* (horizontal and vertical) locations of sensor nodes. This process is shown in the figure 6(a) & (b) given ahead:

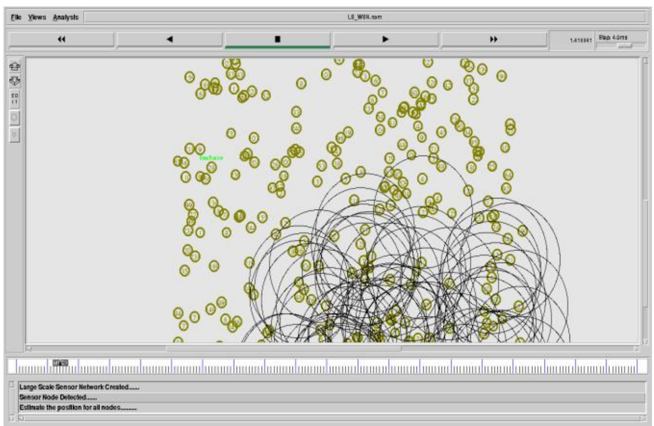

Figure 6(a). *Position Estimation*

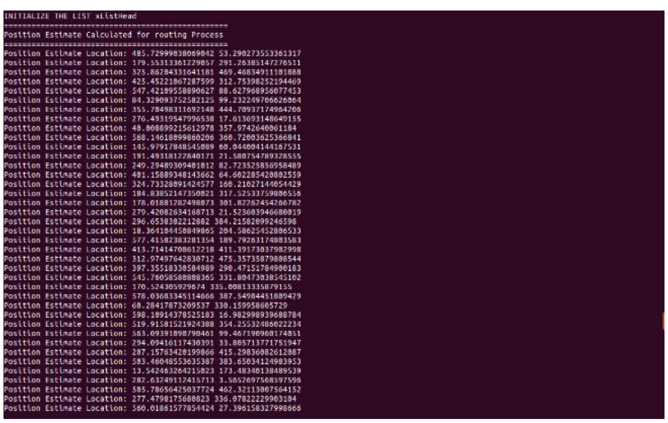

Figure 6(b). *Position Estimate Location*

Figure 6 (a) and (b) provide information about the placement and list of position estimation locations of all sensor nodes respectively.

Data Communication

In this stage, Communication nodes discover the neighbour nodes; transmit the data from the source to destination via Acknowledgement Report. The data transmission process takes place between two or more nodes and during this time communication should be based on energy. If the initial colour of the node changes then it indicates that the energy is reduced during data transmission. Yellow colour means energy reduction of a node. Red colour node signifies that the nodes are into low energy. Red colour nodes need to increase their energy to accomplish communication as in case of the transmission failure occurring in low energy state, the node won't be able to retransmit the data. The process of data communication is given in figures 7 (a) and (b) below.

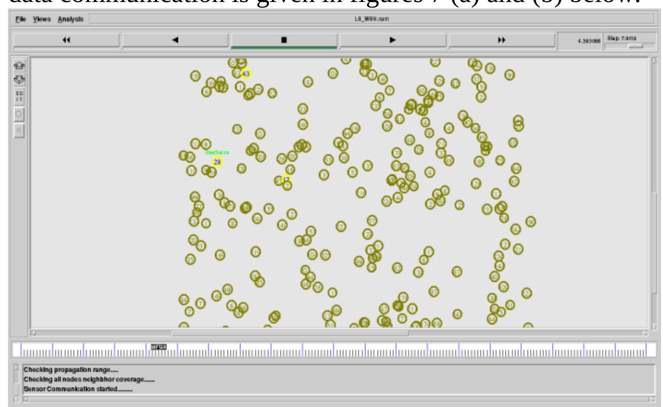

Figure 7(a). *Data Communication*

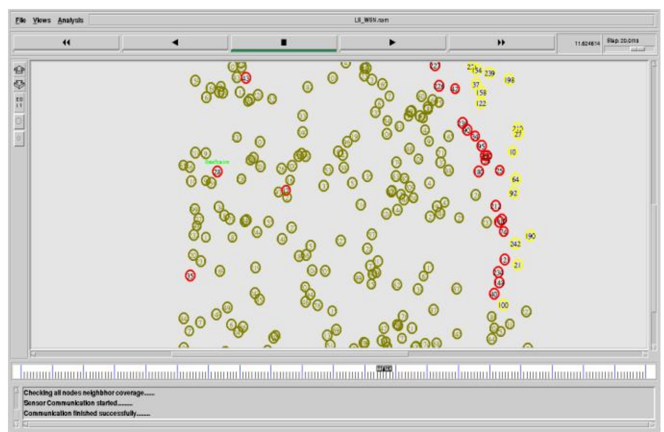

Figure 7(b). *Data Communication showing yellow and red nodes*

Mobility of Nodes

Figure 8 as given below represents the movement of nodes, and during this process, the nodes will move from its initial location to their target location, i.e., from source to destination or sink.

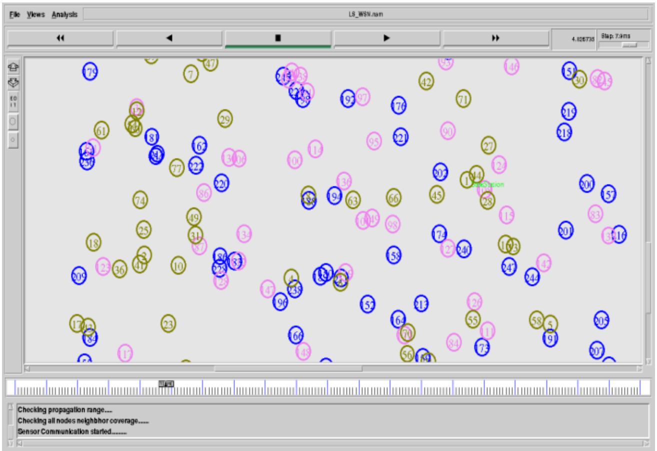

Figure 8. *Mobility of Nodes*

Mobility Location

Figure 9(a) & (b) shows the list of nodes and mobility locations.

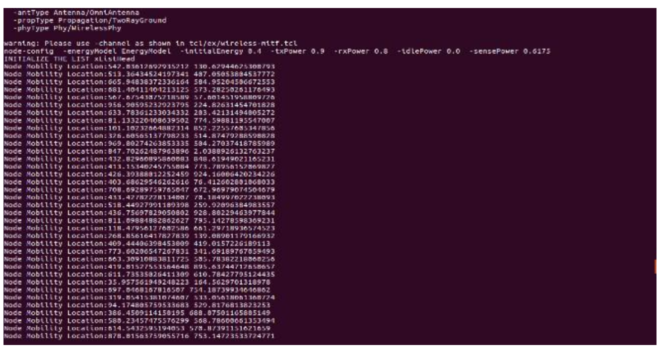

Figure 9(a). *Mobility Location*

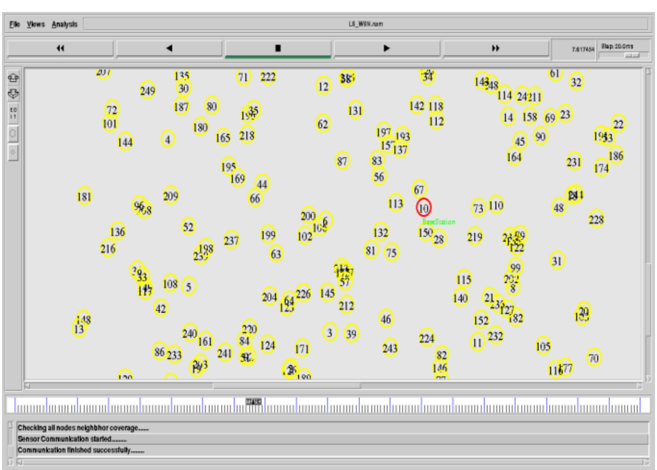

Figure 9(b). *Mobility of Nodes with successful communication*

Figure 9(b) shows that the successful completion of communication and the residual energy status of nodes. After completion of the simulation process, it is necessary to hold some energy. All the nodes showing in yellow colour indicates that nodes still possess some energy and are yet able to send the data.

PERFORMANCE ANALYSIS

Performance Evaluation:

For the performance evaluation process, the performance metrics are to be concluded by means of graphical representation with validation between existing research work and proposed work.

Table 2. Results Validation

Parameter	CLA (Existing)	PELR (Proposed)
Average position error (%)	42	30.5
Energy consumption (%)	24	18
Communication cost	10.08	9.53

Simulation results' graphs are given ahead representing the results as compiled here.

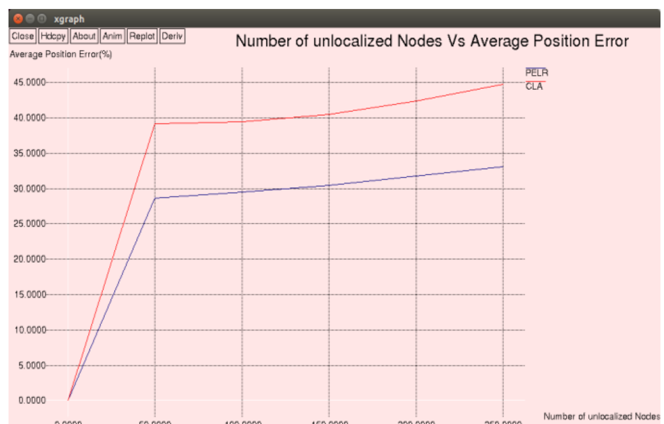

Figure 10(a). *Number of Unlocalized nodes Vs. Average position error*

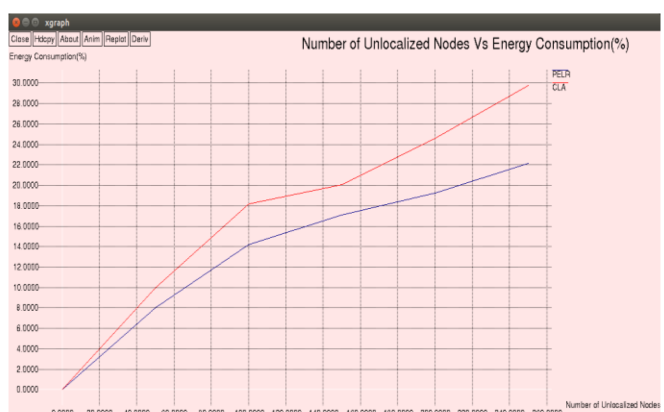

Figure 10(b). *Number of unlocalized nodes Vs. Energy consumption*

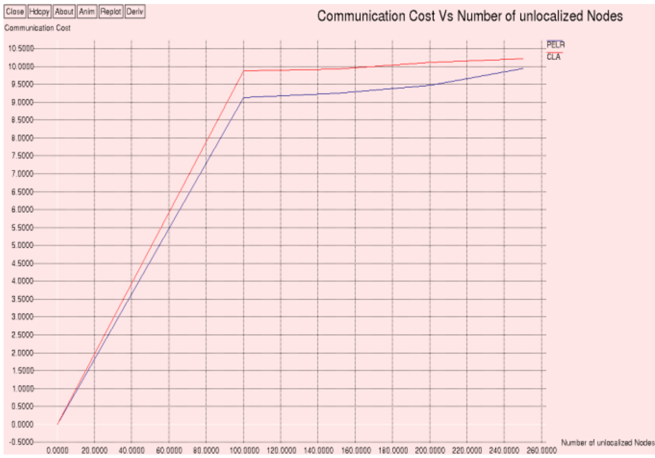

Figure 10(c). *Communication cost Vs. Number of unlocalized Nodes*

In this evaluation, PELR (Position Estimate Localization Routing) shows improvement over CLA (Centroid Localization Algorithm) in terms of

- Lesser number of unlocalized nodes, hence Reduced Node Failure Ratio
- Better Average Position Error figures, hence Increased Accuracy
- Reduced Energy Consumption, hence better Energy Efficiency and Longevity of sensor nodes
- Reduced Communication Cost

VI. CONCLUSION & FUTURE SCOPE

In this research, an efficacious recursive localization method named as Position Estimate Localization Routing has been proposed. From the simulation result plots, it is evident that the proposed PELR method has reduced the average position error, scaled down the consumption of energy and the time of execution in addition to the communication overhead against the existing CLA (Centroid Localization Algorithm) approach. PELR came out to be a better range free localization approach than CLA, enhancing the overall system performance for large-scale WSNs considering the trade-off between location accuracy and time cost.

In this research, we focused on location detection with high accuracy and low cost in a large-scale wireless sensor network but security is not yet considered. In the future, the work can be enhanced with the use of cryptography for security in these located nodes for large-scale wireless sensor networks.

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