ISSN 2319 - 6629
Volume 12, No.1, December 2022 – January 2023
International Journal of Wireless Communications and Networking Technologies
Available Online at http://warse.org/IJWCNT/static/pdf/file/ijwcnt011212023.pdf
https://doi.org/10.30534/ijwcnt/2023/011212023

Mobile Anchor Assisted Effective Node Localization Algorithm for Wireless Sensor Networks

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Received Date: November 11, 2022 Accepted Date: December 09, 2022 Published Date : January 07, 2023

ABSTRACT

Wireless Sensor Network (WSN) is collection of thousands of randomly, spatially distributed low-cost Sensor Nodes (SN) deployed normally in harsh environments. These deployed SNs collects data and delivers to Base Station (BS) located in a remote region. In a sensor network it is necessary to know about the location of sensor node and data collected by that node as it has a strong impact on overall performance of the WSN. An algorithm to transfer data using energy efficient mobile anchor based localization mechanism is presented in this paper. Firstly, the distance between anchor node and unknown node is determined using Received Signal Strength (RSS) and then using Trilateration method location of the unknown node is identified. Proposed algorithm aims to decrease the consumable energy that improves life of the network. Simulation results are compared with the existing localization technique to evaluate performance of the proposed algorithm in terms of energy consumption, packet delivery ratio and control overheads. The proposed scheme performs better than the existing Mobile Anchor Assisted Localization algorithm based on Regular Hexagon (MAALRH) for WSNs.

Key words: Wireless Sensor Network (WSN), Localization, Mobile Anchor, Trilateration, Received Signal Strength Indicator.

1. INTRODUCTION

In most of the applications Wireless Sensor Networks (WSNs) are used to simplify the management of complex problems [1]. For wireless Sensor Nodes (SNs), energy conservation is one of the prime concern in most of its applications because the life time of network mainly depends on the energy consumption in SNs. Therefore, it is very important to conserve and balance the energy consumption. In WSN designing algorithms with minimum energy expenditure [2] is the main challenge.

The main goal of localization is to assign geographic coordinates to every SN in the deployment region [3] that has an unknown position. Location information of the Sensor Node (SN) can be obtained either by recording the location while deploying or using built in Global Positioning System (GPS) for the nodes [4]. It is not possible to record the location information manually, especially for large scale networks.

One of the most important issues in WSN is localization, because location information is necessary for deployment, coverage and target tracking, rescues, routing and location service [5] [6] as shown in figure 1. For example, sensor nodes sense the occurrence of event in sensing region and the sensed information is disseminated via satellite/internet and base station/sink/gateway to the end user. If the event location is not in association with the sensed data, then the user cannot take the immediate action. So the users need to know not only occurrence of the event but also where the interested event is occurring. Because of this reason, node localization is considered as critical issue for WSN.

Determining the localization of nodes in a WSN involves collaboration between sensor nodes. Since localization is essential for routing application, several routing protocols based on the localization are presented in [7] - [10]. The protocols use location information to maintain a gradient field and also utilize multiple paths simultaneously for creating route diversity resulting in increased robustness.

Transmission of data in WSN is more effective when the sensor nodes location is correctly located. Several schemes introduced in [11] - [15] deal with localization and can be classified into two main categories: range free and range based schemes. With known distance or angles between the nodes localization can be achieved in range based mechanisms. Range free mechanisms localize the sensor nodes without the knowledge of angle/distance.

1.1 Contributions

Since localization is such an important factor for sensor nodes, increasing its precision is a critical issue that allows for efficient data transmission between SNs of WSNs and thus reduces energy consumption that enhances network lifetime. Our contributions in the proposed work are as follows:

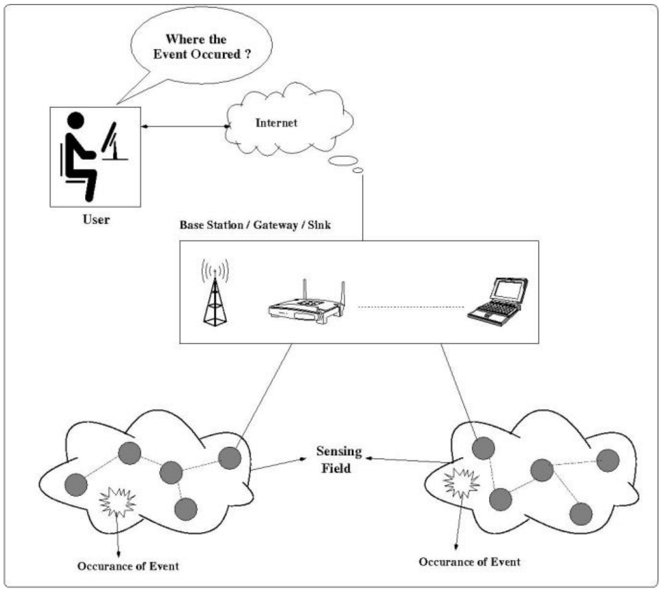

Figure 1: Necessity of Localization for WSN

- Received Signal Strength Indicator (RSSI) or free space path loss between two nodes is estimated using Friis transmission formula. Among various path-loss models, the log-normal model (single-slope model) is used for estimating RSSI. The distance between the known and unknown node is calculated by converting the free space path loss or RSSI to distance.
- Trilateration method is used to estimate xy-coordinates (position) of unknown node using three known nodes and their distances from the unknown node.
- A Mobile Anchor (MA) node is considered that moves around a circular sensing field. Position information collected by cluster head is transferred to base station via MA.
- The mobility of MA is varied at different levels and simulated. The performance of proposed work is found to be better with respect to performance metrics such as end to end delay, energy consumption and throughput.

Rest of the paper is organized as follows. Section II presents related works and section III presents proposed work. Simulation model for proposed scheme and result analysis are discussed in section IV and V respectively. Finally our work is concluded in section VI.

2. RELATED WORKS

The Node Localization Algorithm for WSNs with Mobile Beacon node (NLAMB) is presented in [16] to enhance the accuracy of SNs localization in order to reduce the maximum movement distance of the beacon node. The NLAMB algorithm splits the movement area of beacon node into hexagonal grids and creates an optimization model for reducing localization errors based on the beacon node's movement route and distance constraints. This algorithm is ideal for sensor node distribution scenarios and also lowers average sensor node localization error.

It has been suggested that movable beacons can be used to assist WSN nodes in estimating their locations. A beacon is a node that knows its location (via GPS) and moves around the sensor area. The work in [17] provides a brief description of the various localization strategies used in WSN, as well as an V curve based obstacle avoidance route planning localization algorithm. In the mobile anchor nodes aided localization, mobile path planning is critical. The better the mobile path planning process, the more effectively and reliably the nodes in the monitoring area will estimate their own location.

There are many path planning methods for node localization such as SCAN, Double-SCAN (D-SCAN), Hilbert, MAALRH, Z-Curves, Localization mechanism with a Mobile Anchor node based on Trilateration (LMAT), D-connect and S-CURVES are proposed [18] - [22]. Comparisons of some of the mobile anchor assisted path planning schemes are provided in table 1.

The SCAN model's key advantage is its ease of implementation; however, it suffers from the collinearity issue, which has a major impact on its accuracy [23]. So to overcome the weakness of SCAN and avoid collinearity, Hilbert is proposed [24] which work with division of total area into four identical squares and connecting points between the squares. But the coverage problem is one of the major issues in Hilbert. S-CURVES swap the SCAN model's straight line with an S-shaped curve, essentially reducing collinearity while increasing the length of the moving direction [25].

D-connect is a novel path planning method that assures the localization of all SNs with the shortest possible trajectory length [26]. LMAT is proposed to overcome collinearity and improve accuracy in which is made up of a series of symmetrical triangles [27]. MAALRH is a recent model in which the path begins at the middle and travels in a hexagonal pattern. MAALRH performance is very poor in terms of both localization ratio and error since the mobile anchor is not able to reach corners of the hexagonal area.

In Z-Curves, as name implies the network is covered by mobile anchors in a Z-shape and it works using the concept of trilateration to overcome collinearity problem [28]. Combining SCAN algorithm and mobile anchor based localization algorithm using Trilateration method [29] is proposed to save the mobile anchor node energy by reducing the number of corners along the planned path.

Many localization schemes combine computational intelligence techniques with RSSI and trilateration methods to improve the performance and accuracy. The use of Particle Swarm Optimization (PSO) to propose a new concept of virtual anchor nodes used for localizing target nodes by one anchor node moving in a Hilbert trajectory is presented in [30] - [32].

The Binary-PSO algorithm is employed [33] to assemble a dynamic anchor node set for localizing the unknown nodes. Comparing with the PSO based mechanisms, Salp Swarm Algorithm (SSA) [34] performs better in terms of computing time, localization accuracy and number of localized nodes. The aim of work proposed in [35] is to develop a velocity adaptation based PSO for minimizing localization error.

A novel target tracking algorithm that combines a learning regression tree approach with RSSI-based filtering methods presented in [36] [37]. The work mentioned in [38] [39] is based on the centroid algorithm uses a fuzzy Mamdani and Sugeno inference method that improves the localization accuracy which helps in geographic routing.

The butterfly optimization algorithm, a nature-inspired meta-heuristic algorithm based node localization scheme [40] performance is better when it comes to accuracy and computing time compared to PSO. An improved version of the shuffled frog leaping algorithm is presented in [41] for precise sensor node localization especially in noisy environments. It performs better compared with PSO and artificial bee colony algorithms.

3. PROPOSED SCHEME

This work deals with efficient anchor based node localization to transfer data in WSN. As we know that energy consumption of sensor node directly proportional to the distance. If the distance between source and destination is more, then the energy consumption will increase. So multi-hop technique is employed to reduce the distance. Then energy consumption is reduced by eliminating direct communication from source node to base station. Since Cluster Head (CH) is involved in the process of position information transmission, it is very much important to update the CH periodically. If CH deploys then network fails quickly, so node with highest residual energy selected as CH. Here mobile anchor node is used as intermediate node between CH and base station for transmitting location information.

3.1 Network Environment

The sensor nodes are deployed in circular sensing field and these sensor nodes are divided into three clusters. Depending on the residual energy CH is selected for each cluster. The node with the highest residual energy will be the CH and in case multiple nodes have same residual energy, lowest ID node will become CH. To avoid direct communication between the CH and base station, an intermediate mobile anchor node is considered which moves as shown in figure 2 around the circular sensing field. Calculated position information is collected by CH and in turn transferred to Base Station (BS) via intermediate mobile anchor node.

Table 1: Attributes of Cleveland dataset

Sl. No.	**Protocol**	**Localization Process**	**Localization Method**	**Area**	**Path Movement**	**Path Length**	**Accuracy**
1	SCAN [23]	Distributed	Range-free	2-D	Static	Less	Low
2	Hilbert [24]	Distributed	Range-free	2-D	Static	Medium	Low
3	MAALRH [48]	Distributed	Range-free	2-D	Static	More	Medium
4	Z-Ciruve [28]	Distributed	Range-free	2-D	Static	Medium	High
5	LMAT [27]	Distributed	Range-free	2-D	Static	Medium	High
6	S-Curves [25]	Distributed	Range-free	2-D	Static	More	Medium
7	D-Connect [26]	Distributed	Range-free	2-D	Static	Less	Medium
8	NLA-MB [16]	Distributed	Range-free	2-D	Dynamic	Medium	High

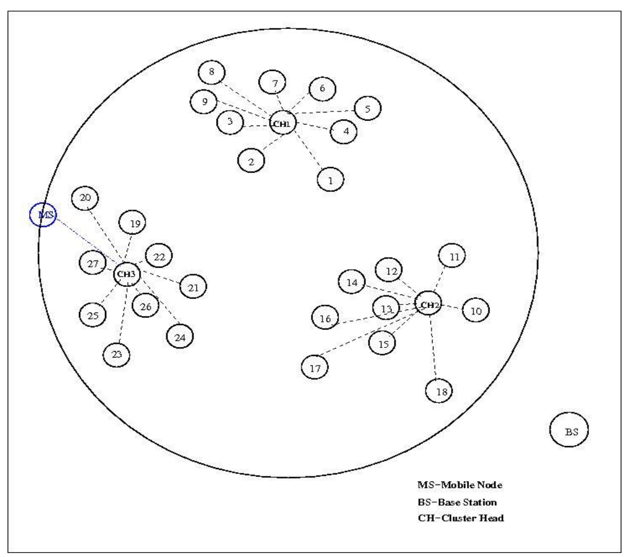

Figure 2: Movement of MA node

When Mobile Anchor (MA) comes nearer to the base station while moving along circular sensing field, it transfers all the position information collected from the CHs of all three clusters which is shown in figure 3. MA speed can be varied according to our convenience for the effective data transmission. In the proposed scheme, initially the distance between known and unknown node is calculated using RSSI. Then trilateration method is used to determine the coordinates of the unknown node using the calculated distance. Then the calculated position information is transferred to base station via intermediate MA node moving around the circular sensing field.

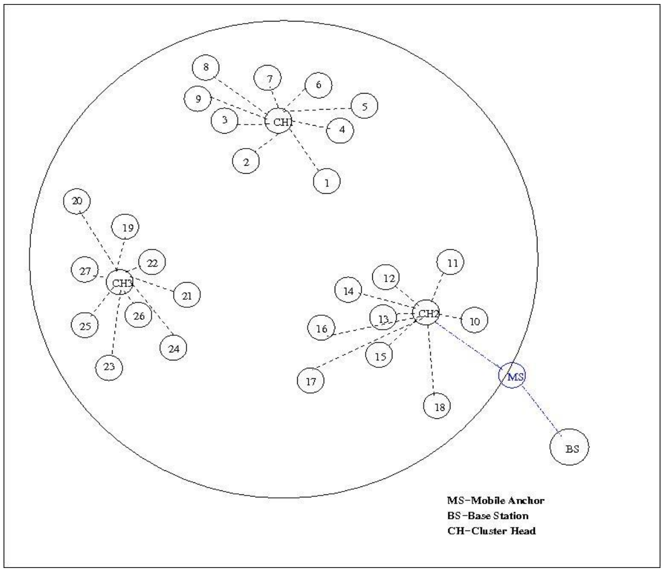

Figure 3: Transfer of Data to BS via MA node

3.2 Distance measurement using RSSI model

Usually the signal received at receiver is observed as a function of distance, frequency and antenna properties [42] which is represented using in equation (1) as:

$$P_{Rxd} = f(d, f, P_a) \tag{1}$$

Where P_{Rxd} is strength of the received signal (power), f is operating frequency, d is the distance between the transmitter and receiver, and P_a indicates properties of antenna such as gain.

Since P_{Rxd} has several components such as scattering, shadowing, reflection including Line-of-Sight (LOS), RSSI can be modeled using equation (2).

$$P_{Rxd} = PL(d) + \psi + \alpha \tag{2}$$

Where $PL(d)$ is the probabilistic element of the signal, which can be represented by a variety of path-loss models, including the single-slope model (log-normal model), Hata Model, Stanford University Interim (SUI) Model, and Okumura's Model. ψ (random variable that predicts the variation in the received signal in obstructed environment) large scale fading also known as shadowing and α is small scale fading also known as multi-path caused due to attenuation, scattering diffraction of the receiving signal.

- Let us consider anchor or known node P(x, y) and unknown node U(x, y). Free space path loss or RSSI can be calculated using Friis Transmission formula [43] using equation (3).

$$PL(d) = PL(d_0) - 10n\log\left(\frac{d}{d_0}\right) \tag{3}$$

Where $PL(d)$ is the RSSI or free space path loss at the receiver in dB, $PL(d_0)$ is the average RSSI strength at the reference distance d_0 [44] [45] in dB, n is the path loss exponent, and d is the distance [46]. $PL(d_0)$ is governed by transmitted power and operating frequency and is given by equation (4).

$$PL(d_0) = P_{Txd} - K\left(\frac{d}{d_0}\right) \tag{4}$$

Where

$$K = 20\log\left(\frac{\lambda}{4\pi d_0}\right) \tag{5}$$

P_{Txd} is the transmitted power and λ the wavelength of the signal being transmitted.

- Once the free space path loss is known, then it can be converted to distance as shown in equation (6).

$$d = 10^{\frac{PL(d)-PL(d_0)}{20}} \tag{6}$$

3.3 Localization by Trilateration

Let us consider the known or static anchor nodes P(x_1, y_1), Q(x_2, y_2) and R(x_3, y_3) as shown in figure 4 with distance m_1, m_2 and m_3 respectively from the unknown node U(x, y).

The distance between known and unknown nodes is calculated using equation (6). Applying Trilateration method position (xy-coordinates) of unknown node U(x, y) is estimated by determining the intersection of three circles as follows:

$$(x - x_1)^2 + (y - y_1)^2 = m_1^2 \tag{7}$$

$$(x - x_2)^2 + (y - y_2)^2 = m_2^2 \tag{8}$$

$$(x - x_3)^2 + (y - y_3)^2 = m_3^2 \tag{9}$$

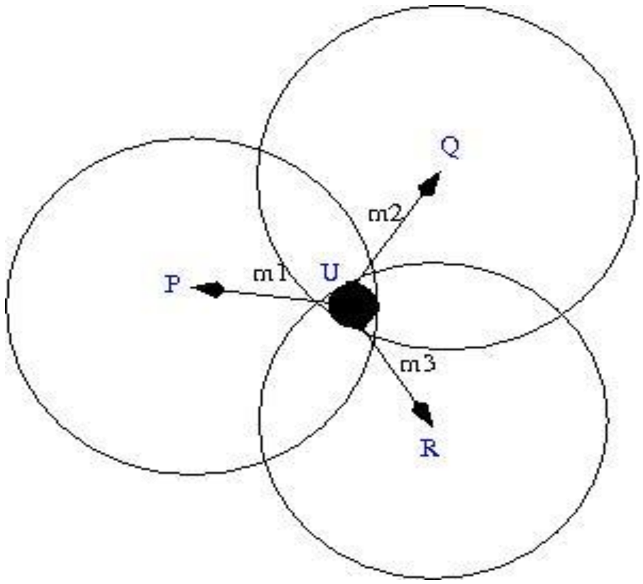

Figure 4: Intersection of circles in Trilateration method

Further solution for the equations (7), (8) and (9) is as follows:

$$x_1^2 - x_3^2 - 2(x_1 - x_2)x + y_1^2 - y_3^2 - 2(y_1 - y_2)y = m_1^2 - m_3^2 \quad (10)$$

$$x_2^2 - x_3^2 - 2(x_2 - x_3)x + y_2^2 - y_3^2 - 2(y_2 - y_3)y = m_2^2 - m_3^2 \quad (11)$$

The equations (10) and (11) can be represented in matrix form as *SX=W*, where S, *X* and *W* are given by equations (12) - (14) respectively as:

$$S = \begin{bmatrix} 2(x_1 - x_2) & 2(y_1 - y_2) \\ 2(x_2 - x_3) & 2(y_2 - y_3) \end{bmatrix} \quad (12)$$

$$W = \begin{bmatrix} x_1^2 - x_3^2 + y_1^2 - y_3^2 + m_3^2 - m_1^2 \\ x_2^2 - x_3^2 + y_2^2 - y_3^2 + m_3^2 - m_2^2 \end{bmatrix} \quad (13)$$

$$W = \begin{bmatrix} x \\ y \end{bmatrix} \quad (14)$$

The equation can be solved using the least square method. The location (xy coordinate) of the unknown node U(x, y) is determined using equation (15) as:

$$X = (S^T S)^{-1} S^T W \quad (15)$$

In the proposed scheme, the location information of the sensor node is communicated to the base station effectively using the MA node that moves around the circular sensing field with predefined convenient speed.

4. SIMULATION

We have used "C++" programming language as discrete event simulator to simulate the proposed scheme. Initially appropriate network environment is created with random deployment of the sensor nodes. The 'N' numbers of deployed Sensor Nodes (SN) are grouped in three clusters by dividing into 3 integer parts and left out nodes will be added to third cluster. Energy is allocated to sensor nodes randomly and clustered nodes made into to fall in a circular sensing area. With the help of MA (as intermediate node between CH and BS), the location information of the unknown node is communicated to BS or end user. Depend upon the residual energy of the SN, CH updated periodically. Simulation procedure and performance parameters are presented in this section.

4.1 Simulation Procedure

Some of the parameters considered for simulation are listed in table 2 and simulation procedure for the proposed scheme is summarized in Algorithm 1.

Algorithm 1: Simulation Procedure

Begin
Calculation of RSSI Using equation (3)
Computation of distance (d) using equation (6)
Enter the co-ordinates of three anchor nodes
Enter the distance (d) of anchor nodes
Computation of position (xy coordinates)
Enter the number of nodes
Create clusters
if energy of SN ≥ threshold value then
Select CH
else if Choose SN with energy ≥ threshold value then
Update the CH
end if
if Mobile Anchor nearer to CH then
Transfer Position information to MA
else if Collect position information from SNs then
Sleep until MA arrival
end if
if MA nearer to BS then
Transfer information to BS
end if
Compute the performance metrics

4.2 Performance Parameters

To evaluate the performance of proposed work, the following performance metrics are considered.

Table 2: Simulation Inputs

Sl. No.	Parameters	Specifications
1	Number of nodes [N]	10 - 60
2	Simulation area in meters [A]	100 * 100
3	Packet size [Ps]	128Kbyte
4	Transmission Range	100m
5	Number of mobile Anchors [MA]	01
6	Anchor Mobility (Minimum)	5m/s
7	Anchor Mobility (Maximum)	15m/s
8	Channel Type	Wireless
9	Number of Clusters	03
10	Sensing Field	Circular

- **End to end delay:** It is the time taken for a network to transmit data from CH to BS via mobile anchor, measured in milliseconds (ms).
- **Packet Delivery Ratio (PDR):** It is defined as the ratio of total number of packets successfully received by base station to the total number of packets sent by mobile anchor node including retransmissions. PDR is expressed in percentage.
- **Energy consumption:** It is the energy used by the sensor nodes, cluster heads, and mobile sinks to transfer data from source node to BS via mobile anchor. The amount of energy consumed is measured in milli Joules (mJ).
- **Overhead:** Control overhead (ratio of control packet bits to data packet bits) and packet overhead (fraction of bits in every sensor data packet that are not data) are the two types of overhead. When it comes to determining the position of nodes, overhead becomes one of the major issues [47]. In general, overhead is considered as the total number of bits transmitted per successfully delivered data and expressed in bits (b).
- **Throughput:** It is the ratio of total number of bits received successfully to the total simulation time and expressed in bits/milliseconds (b/ms). It gives the average rate at which data packets are delivered successfully over a communication network.
- **Bandwidth Utilization:** It is the percentage of bandwidth utilized out of the total available bandwidth. Effective utilization of the available of the bandwidth leads to reduction in network congestion. It is expressed in terms of percentage.

5. RESULT ANALYSIS

The simulation results of proposed work are compared with the Mobile Anchor Assisted Localization algorithm based on Regular Hexagon for Wireless Sensor Networks [48] referred as MAALRH in the graphs. End to end delay with varying number of nodes and anchor mobility is depicted in figure 5. It is observed that, end to end delay for the proposed scheme is less than the MAALRH. There is reduction in the delay as the mobility of the anchor increases due to faster transmission of data from anchor to base station.

The total number of packets received (PDR) by the base station from the source node for both proposed and MAALRH scheme is shown in figure 6. Since rotation speed of the mobile anchor around the sensing field increases, CH will get less time to transfer the data to the mobile anchor. So as we increase the mobility of the anchor node, number of packet drop will be more which results in reduction of PDR. When we compare the results, it is seen that the total number of packets received for the proposed scheme is higher than MAALRH.

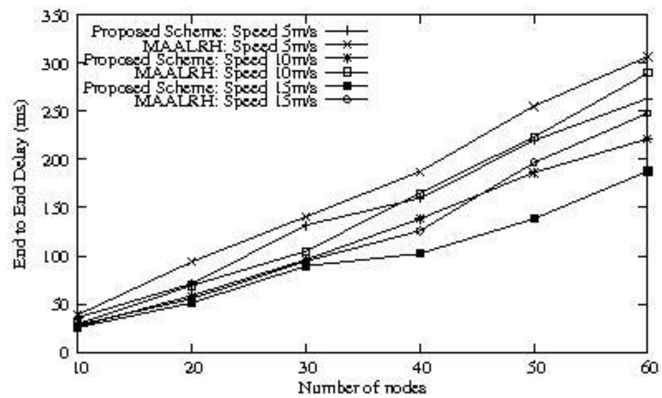

Figure 5: Number of Nodes Vs. End to End Delay

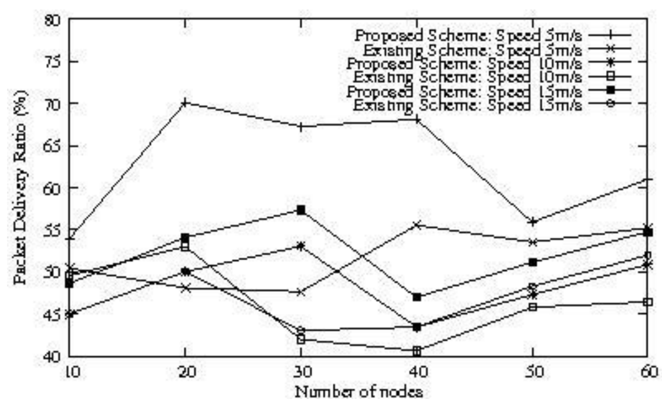

Figure 6: Number of Nodes Vs. Packet Delivery Ratio

Conventionally, as network grows (increased number of nodes) the amount of energy consumed will also increase. The energy consumption by both proposed and MAALRH scheme with varying anchor mobility is shown in figure 7. It is seen that, performance of the proposed scheme is better than the MAALRH in terms of energy consumption and increase in mobility lowers energy consumption which is due to the reduction in PDR. As a result of the lower energy consumption, the network lifetime can be extended.

Figure 8 outlines the overheads for varying number of nodes along at different mobile anchor speed for proposed and MAALRH schemes. It is observed that the overheads increases as number of node increases but comparing to existing scheme there is reduction in overheads for the proposed scheme. As the mobility of the mobile anchor increases, overheads will also increase due to reduction in PDR.

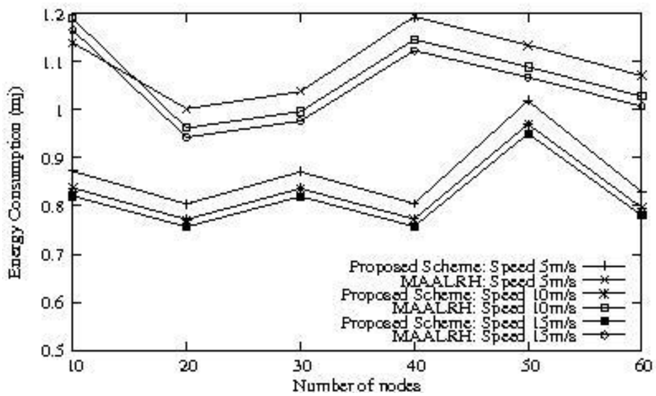

Figure 7: Number of Nodes Vs. Energy Consumption

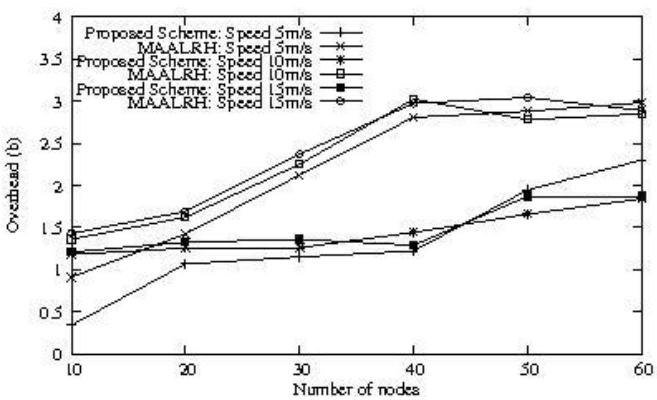

Figure 8: Number of Nodes Vs. Overheads

Throughput for various number of nodes under different speed levels of the mobile anchor is illustrated in figure 9. As the number of nodes increase, throughput also increases gradually. It is observed that there is reduction in throughput as increase in mobility because of decrease in the delay at higher mobility levels of mobile anchor. Comparing with the MAALRH scheme, there is improvement in the throughput of the proposed scheme.

Utilization of the available bandwidth for different number nodes with variation in the mobility of mobile anchor is depicted in figure 10. Usually the bandwidth utilization will be more for higher number nodes but it decreases as mobility of mobile anchor increases as shown in the graph. This is due to increase in the overheads. The bandwidth utilization is less for the proposed scheme as compared with MAALRH scheme.

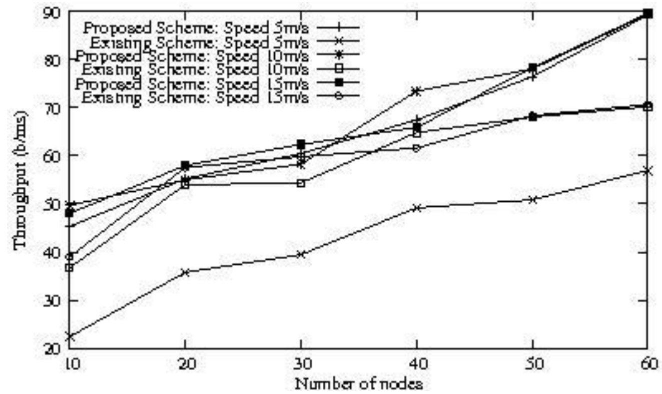

Figure 9: Number of Nodes Vs. Throughput

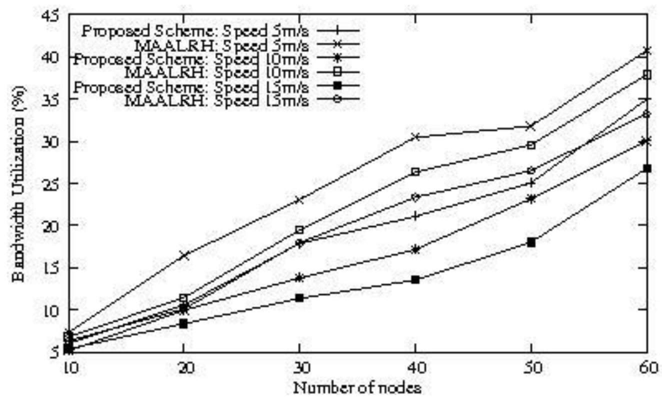

Figure 10: Number of Nodes Vs. Bandwidth Utilization

6. CONCLUSION

WSN is essential in a various fields that include defense, health, agriculture, the environment, and communication. Our proposed scheme i.e., mobile anchor assisted effective node localization algorithm for position information transmission in wireless sensor networks depicts efficient way to reduce energy consumption by using multi-hop technique since energy is a critical parameter among the available resources which has to be used effectively. We have also analyzed the performance metrics such as end to end delay, overhead, throughput, bandwidth utilized and packet delivery ratio by varying different number of nodes. It is observed that, our proposed scheme performance is better as compared to the MAALRH algorithm.

Mobile anchor speed is varied at different levels and it is seen that, at higher speed levels throughput, end to end delay, energy consumption is improved compared with existing MAALRH scheme. In our work, only one mobile anchor and three clusters are considered. In future increased number of clusters and mobile anchor node can be considered to improve the network performance.

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