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Improved DV-Hop Localization Algorithm for Wireless Sensor Networks

Jamal Kutty, Kanika Sharama

Abstract: ***Considering the emerging applications of Wireless Sensor Network, the localization of sensor nodes is very important in some applications. Hence in this paper, proposed an improved Distance-Vector hop technique to reduce the localization error generated in the classical method of range free DV-hop algorithm. The proposed algorithm targets to minimize the error introduced in the average hop-size value by the series of mathematical corrections like minimum mean squared error method, modifying the average hop-value value calculated between known sensor nodes with respect to error-term calculated by comparing the estimated distance with actual distance or Euclidean value of anchor nodes, by using dynamic coefficient of weight with respect to minimum number of hopes, calculating x and y co-ordinates of unknown by using 2-D-hyperbolic method. The final corrections on the x and y values are done by using some geometrical methods. Simulations and results are executed on three different evolution models of network by varying radius of communication range, anchor node percentage and number of sensor nodes.***

Keywords: ***DV-Hop, localization, range-free, wireless sensor networks.***

I. INTRODUCTION

Wireless Sensor Network is a network of low cost sensor nodes for the purpose of monitoring or sensing some particular information around the distributed area [1]. The main blocks of sensor networks builds with processor, power section and transceivers. Nowadays the application of this types of sensor network includes military side, traffic monitoring, agricultural lands, automating buildings, disaster monitoring, airport surveillance, etc. [1]

In some applications the (x, y) values of sensor nodes is important along with the monitored data from the sensor nodes, hence some methods are employed for this purpose. The method or algorithm to find the sensor node co-ordinates is referred to as localization in WSN [2]. Localization with the help of GPS or by using manual configurations is practically not possible in large sensor nodes due cost, energy, size and indoor problems [2]. Hence research on localization field is increased in large extent to solve this problem with limited cost and energy. By considering the parameters like cost, energy, accuracy and size the researchers developed different methods of algorithm to catch this problem. Due to the large number of algorithm the localization is classified into many categories and one of the important classifications is range-based and range-free classification [3]. In range-based the (x, y) values of sensor nodes are calculated with the help of distance/angle information which is obtained with the additional hardware used along with sensor nodes [9], which increases the cost, size and energy requirements of the overall system. Hence this system is used only where the accuracy is the prime factor. Commonly used algorithms are Time-of-Arrival (ToA), Ange-of-Arrival (AoA) and RSSI [9]. In range-free methods, the distance value is estimated with the help of built-in connectivity hardware available in the sensor node, so this type of designs are cheap and simple but the position accuracy is less compared to former one. DV-hop, Approximate Point-In Triangle (APIT), Centroid, etc. [4] are commonly use range-free localization methods.

Due to cheap and simplicity most of the researchers are concentrated on range-free classical DV-Hop algorithm and to make progress on localization accuracy. In classical DV-hop [4], initially all anchor nodes floods a packet which contains (x, y) co-ordinates of anchor sensor nodes and hop-counter value and hop-counter is incremented from each node. By using the (x, y) co-ordinates and minimum hop-counter, each known sensor node determines average-hop-value value and this value is forwarded again in the network which helps each target sensor nodes to estimate distance from the known sensor nodes and by using this estimated distance value from the nearby anchor sensor nodes, the target node calculates its (x, y) co-ordinates with the help of maximum-likelihood, trilateration/triangulation methods [5]. But the distance calculated by using average-hop-value introduces some error and this error propagates more in further calculations.

To refine the error in average-hop-size which is calculated in classical dv-hop, an improved method is introduced. For this initially the mean-hop-size is refined by using minimum mean-square error and successive filtering is done by an error factor and dynamic weight coefficient. The error occurred due to loss of quadratic terms in classical dv-hop is tried to clear by using 2-D hyperbolic method [6]. The final accuracy improving is done by using some geometrical methods on (x, y) co-ordinates [6]. The proposed method is simulated in random topology, B-A topology network and small world topology and the result is discussed with classical dv-hop to understand the change in accuracy.

The rest of the sections are arranged for related review works

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in Section 2 and Section 3 explains the classical dv-hop and improvements to define proposed algorithm and the last two sections are used for simulation plots for each topology and conclusion.

II. RELATED WORKS

This section presents related work focusing on the important range-free algorithm related with DV-Hop algorithm.

Shikai Shen et al [6] in this paper, the accuracy of localization is obtained by using Amorphous method and the result is improved by some add-on features like the anchor nodes are selected by setting a threshold hop-count value. For this purpose the probability of beacon nodes in a particular area is calculated by using Poisson distribution method and the unknown node co-ordinates are calculated by using 2D-hyperbolic method instead of the trilateration or least square method.

Xiu-wu Yu et al [7], in this paper the error generated in classical DV-Hop, while calculating the distance value between beacon node and target node is reduced by using error-correction method and multi-hop techniques. In this method the average hop-size error is reduced by using error factor which is connected with hop-count and distance among known sensor nodes. And the distance among target-node and beacon node is estimated with respect to the relative position of anchor nodes. That is if anchor node is nearest, then it simply multiplies the average size by hop-count. And if the beacon node is greater than the minimum hop-count, the calculation is done by comparing angles. And the hop is in-between above two cases, some scaling factor is used to find the distance. The x and y values of unknown node is measured by taking ratio between square of the distance of target node and beacon node. And finally the result is evaluated by using average error in localization and relative accuracy of positioning.

Yuan Liu et al [8], the average-hop value calculated between the beacons nodes are updated by using hybrid localization techniques with the help of optimization called Bat DV-Hop (BADV-Hop) upon the normal DV-Hop methods. The merits of this technics are, it is very simple model, search capability is global, comparatively quick convergence and the accuracy obtained is improved. BA is one of the searching methods in random manner and it detects the targets and neglects the obstacles by using natural ultrasounds. Here the optimization is implemented by using three levels called initialization of groups, which is initialize the velocity and location of each bat. Here the solution is to find out the bat location, which is optimized by updating the bat parameters for best solution.

Yan Chen et al [10], In this paper the localization accuracy is enhanced by using MMSE(minimum mean-square error) method to measure the hop-value between anchor sensor nodes instead of average square error method used in classical DV-Hop technic. And again the output is refined by an error factor and dynamin weight factor which is connected with minimum hop count. And in the final stage the x and y coordinates are measured by 2D Hyperbolic method instead of MLE (Maximum likelihood estimation), which reduces the error generated during the subtraction of the equations hence loss of the quadratic term in the target nodes. This method also used different topologies to study the performance. The research work in this paper is improved by using some geometrical methods and also analyzed the localization error with respect to communication radius, anchor percentage and varying number of nodes.

III. IMPROVED DV-HOP LOCALIZATION ALGORITH

Proposed design used additional changes on average-hop-size calculated by classical dv-hop technique between anchor sensor nodes to enhance the (x, y) co-ordinates of unknown sensor nodes distributed in WSN. The additional steps start with minimum MSE to recalculate the mean-hop-value of known sensor nodes, error term factor is used to further modify the result of MMSE recalculation and coefficient of dynamic weight is used to enhance mean-hop-size between unknown sensor nodes and known sensor nodes. And the (x, y) co-ordinates of target sensor nodes are calculated by using 2-D hyperbolic method. The further reduction of error occurred in (x, y) co-ordinates is done the geometrical method.

A. Classical dv-hop method

The proposed method introduced additional changes on hop-value calculated between known sensor nodes by using classical dv-hop methods [10]. In classical dv-hop technic the hop-value is find out by using two steps. In first step all anchor sensor nodes floods with a packet containing the co-ordinates of anchor sensor nodes and hop-counter value resettled to one. Each sensor node maintains a table for storing the co-ordinates of anchor sensor node and minimum hop-counter value. By using the (x, y) co-ordinates and hop-counter value between anchor sensor nodes, each anchor sensor nodes calculates its hop-size by using the following formula

$$hopsize_j = \frac{\sum\sqrt{(x_j - x_k)^2 + (y_j - y_k)^2}}{\sum h_{jk}}, (j \neq k) \quad (1)$$

Where (x_j, y_j) is the co-ordinates of the jth anchor sensor nodes and (x_k, y_k) is the k th anchor sensor node co-ordinates, (h_{jk}) is the hop number between anchor sensor node (j) and (k)

In classical method this hopsize value is used to estimate the distance among target sensor nodes and anchor nodes to calculate (x, y) co-ordinates of target or unknown sensor nodes. But in proposed design, the following corrections are introduced on hopsize to reduce the weight error.

B. The mean hope-size of anchor nodes by mmse

The MMSE method helps to estimate the average-hop-value among known sensor nodes to reduce the percentage of error by using the formula [10]

$$f_{mse} = \frac{1}{M-1}\sum_{j \neq i}(d_{ij} - Hopesize_i^{ref}.h_{ij}) \quad (2)$$

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Where M indicates the total count of anchor sensor nodes, d_{ij} is i[th] and j [th] anchor sensor node distance in actual, h_{ij} indicates hop count for the same.

Hence the partial derivative for $Hopesize_i^{ref}$ is given by [10]

$$\frac{\partial f_{mse}}{\partial Hopesize_i^{ref}} = \frac{2}{\mathrm{M}-1}\sum_{j\neq i}(Hopesize_i^{ref}.h_{ij}^2 - d_{ij}.h_{ij}) \qquad (3)$$

By minimizing the error, the average-hop-size becomes

$$Hopesize_i^{ref} = \sum_{j\neq i}(d_{ij}.h_{ij}) \Big/ \sum_{j\neq i} h_{ij}^2 \qquad (4)$$

Next modification is done by using error factor, which is calculated as

$$errorfactor = d_{ij}^{est} - d_{ij} \qquad (5)$$

Where d_{ij}^{est} shows estimated anchor node distance between i[th] and j[th] anchor sensor nodes

$$d_{ij}^{est} = Hopesize_i^{ref}.h_{ij} \qquad (6)$$

Hence error per hop among M anchor sensor nodes is given by [7]

$$errorfactor_i^{ref} = \sum_{i\neq j}(errorfactor_{ij}/h_{ij})/(\mathrm{M}-1) \qquad (7)$$

So the modified average-hop-size with the help of error factor is

$$hopsize_i^{mod} = Hopesize_i^{ref} - errorfactor_i^{ref} \qquad (8)$$

In the following equation the average-hop-value between known sensor node is refined by using dynamic weighted coefficient (α_i) , which is connected with minimum hop count (hop) [10]

$$\alpha_i = \left[\frac{1}{hop_i}\right] \Big/ \sum_{j=1}^{M} \left[\frac{1}{hop_j}\right] \qquad (9)$$

$$hopsize_x = \sum_{i=1}^{M} \alpha_i.hopsize_i^{mod} \qquad (10)$$

This final average-hop-size is used to find the distance (d_{xi}^{mod}) between target sensor node and anchor nodes as given below

$$d_{xi}^{mod} = hop_i.hopsize_x \qquad (11)$$

Where (d_{xi}^{mod}) shows the estimated length between target sensor node x and anchor sensor node i.

C.Localization of unknown node

Let (x, y) be the unknown sensor node co-ordinates and (x_1, y_1) to (x_M, y_M) indicates the M anchor sensor node co-ordinates. The 2D hyperbolic equations (12) given below used to estimate the unknown sensor node x and y value co-ordinates [10]

$$(x_1 - x)^2 + (y_1 - y)^2 = (d_{x1}^{mod})^2$$

$$(x_2 - x)^2 + (y_2 - y)^2 = (d_{x2}^{mod})^2 \qquad (12)$$

$$\vdots$$

$$(x_M - x)^2 + (y_M - y)^2 = (d_{xM}^{mod})^2$$

The expansion of the formula(12) is given by

$$-2x_1x - 2y_1y + x^2 + y^2 = (d_{x1}^{mod})^2 - (x_1^2 + y_1^2)$$

$$-2x_1x - 2y_1y + x^2 + y^2 = (d_{x1}^{mod})^2 - (x_1^2 + y_1^2) \quad (13)$$

$$\vdots$$

$$-2x_1x - 2y_1y + x^2 + y^2 = (d_{x1}^{mod})^2 - (x_1^2 + y_1^2)$$

The formula(13) is reorganized into matrix form to find (x, y) co-ordinates as

AX=b (14)

Where $X = (x, y, k)^T, k = (x^2 + y^2)$

$$A = \begin{pmatrix} -2x_1 & -2y_1 & 1 \\ \vdots & \vdots & \vdots \\ -2x_M & -2y_{M1} & 1 \end{pmatrix} \quad b = \begin{pmatrix} (d_{x1}^{mod})^2 - (x_1^2 + y_1^2) \\ \vdots \\ (d_{xM}^{mod})^2 - (x_M^2 + y_M^2) \end{pmatrix}$$

Hence the above formula(14) can be solved to find the co-ordinates is given by

$$X = (A^T A)^{-1} A^T b \qquad (15)$$

By solving the above equation, we get three values including k. The other two values are not exactly equal to (x, y) co-ordinates and hence represented as (x_p, y_p) because $\neq (x_p^2 + y_p^2)$, hence it indicates some error is accumulated during the solving of unknown values. So it is required to reduce the error between $(x^2 + y^2)$ *and* $(x_p^2 + y_p^2)$. Hence to reduce the position accuracy by using (x_p, y_p) with the help of parameter k is given by

$$t = \sqrt{\frac{k}{x_p^2 + y_p^2}} \qquad (16)$$

Hence the new (x_e, y_e) co-ordinates for unknown node is obtained by using k are given below

$$x_e = t.x_p$$
$$y_e = t.y_p \qquad (17)$$

So the target sensor node (x, y) co-ordinates are calculated with the help of (x_p, y_p) and (x_e, y_e). From the above co-ordinates, it is clear that the weight of (x_p, y_p) is comparatively larger than (x_e, y_e). Hence it is approximated as the weight of (x_p, y_p) is double to (x_e, y_e) after checking the repeated simulation. So the final (x, y) values are calculated by

$$x = \frac{2x_p + x_e}{3}$$
$$y = \frac{2y_p + y_e}{3} \qquad (18)$$

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D.Geometrical improvements

Geometrical improvements[13] on (x, y) co-ordinates is done after estimating the (x, y) co-ordinates by using 2-D hyperbolic method, this process is completed by using three steps.

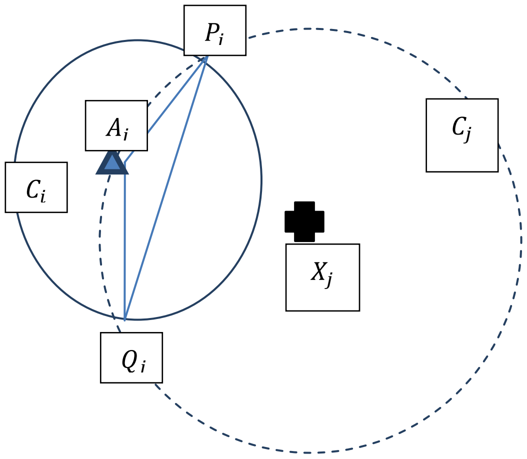

Fig. 1 Localization by using geometrical method

In step (1), unknown sensor node X_j and anchor sensor node A_i is selected for the process. Where anchor sensor node is selected by using least hop number with unknown sensor node. And (x_i, y_i), (x_j, y_j) represents the co-ordinates of anchor sensor node and unknown sensor node respectively.

During step (2), two circles are constructed around anchor sensor node A_i and unknown sensor node X_j and represented as C_i, C_j. The radius of the circle C_j is the distance calculated among the anchor sensor node and target sensor node. The radius of the circle C_i is the distance estimated by using average-hop-value and minimum hops number between unknown sensor node and anchor sensor node as given below

$$R_i = avg\_hop\_size_i * hop_{ij} \quad (19)$$

$$R_j = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (20)$$

During step 3 processing, the intersection co-ordinate points of two circles C_i and C_j are calculated. By using the intersection co-ordinates $P_i\,(x_{pi}, y_{pi})$ and $Q_i\,(x_{qi}, y_{qi})$ with anchor sensor co-ordinate $A_i\,(x_i, y_i)$ a triangle is formed and the newly obtained unknown sensor node co-ordinate is calculated by using the centroid equation of a triangle as given below

$$(x_{new}, y_{new}) = \left(\frac{x_i + x_{pi} + x_{qi}}{3}, \frac{y_i + y_{pi} + y_{qi}}{3}\right) \quad (21)$$

IV. RESULT AND DISCUSSION

All the simulations are carried out by using the software Matlab and the area defined for WSN simulation to find out x, y values of unknown sensor nodes are fixed to 100mX100m units. To measure the improvements of the proposed algorithm on calculating the x, y values of target nodes is tabulated with classical dv-hop, dv-hop with updating and without updating. The Matlab simulations are done in BA model, random model network, and finally small world networks and plotted the localization error with respect to three parameters, total sensor nodes defined in 100mX100m simulation area, anchor node percentage and sensor node communication radius. Out of this parameters the range of communication for each sensor nodes are assumed to be circle. The average error in localization is measured by the equation,

$$LE = \frac{\sum_{i=1}^{N-M} \sqrt{(x_i^e - x_i)^2 + (y_i^e - y_i)^2}}{R * (N - M)} \quad (22)$$

Where N indicates the complete sensor nodes defined in the 100mX100m simulation part and M indicates the anchor sensor nodes, and R is the radius for the circular communication range in the simulation area, (x_i^e, y_i^e) and (x_i, y_i) are the estimated and actual (x, y) co-ordinates of i^{th} unknown sensor nodes or target sensor nodes distributed in the simulation area.

A.Simulation Analysis of random network with respect to communication radius

In this experiment, the simulation is carried out by varying the communication range radius of each sensors varied from 15m to 35m, the whole number of sensor nodes in 100mx100m area are fixed to 200 and strength of anchor sensor nodes are maintained as 10% of whole sensor nodes. From fig. 1.1 it is clear that the wireless connectivity of sensor nodes rises with respect to communication range radius, this indirectly reduces the average-hop size error. So the values calculated for x, y co-ordinates of unknown will be closer to actual x, y values of unknown sensor nodes, hence the error is reduced during localization process and from the graph the proposed algorithm gives good result in localization accuracy.

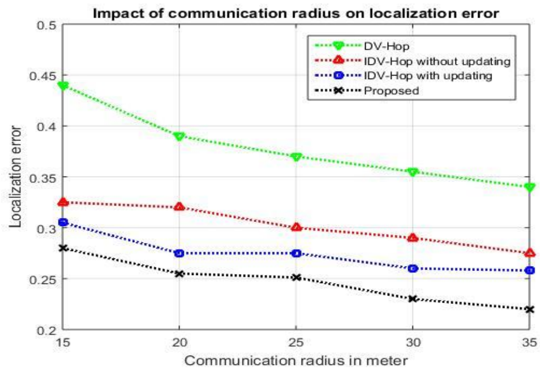

Fig. 1.1 The effect of radius range in communication on localization error

B.Simulation Analysis of random network with respect to anchor percentage

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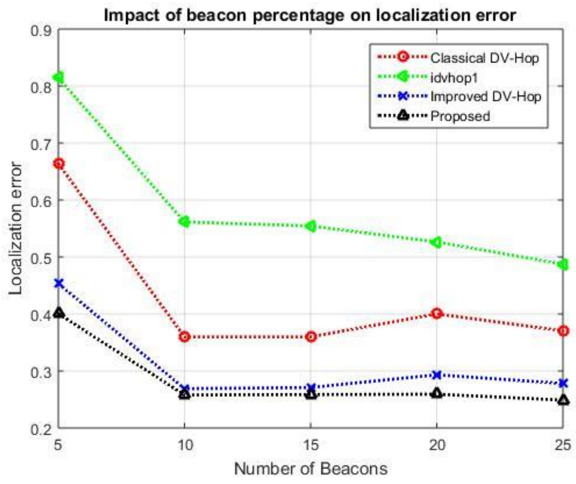

Fig. 1.2 The effect of known sensor percentage on average localization error

In this graph the communication range radius and sensor nodes are initialized into 15m and 200 respectively and known sensor nodes are changed from 5 percentages to 25 percentages of sensor nodes. At 5% level of anchor sensor nodes the error in localization is high due to the less number of anchor nodes in the network, that is 10 anchor nodes are present in the 100mx100m area, which produces a large average hop-value error between known sensor nodes. So the distance calculated by using this hop-size error accumulate more error while calculating (x, y) values of unknown sensor nodes. When the anchor sensor node percentage increases, it helps to reduce the number of hop between the unknown sensor node and anchor sensor nodes. So difference between calculated distance and actual distance is less, so the accuracy of the position calculated for unknown sensor nodes is high. From fig.1.2, the proposed method gives comparatively good accuracy in localization.

C.Simulation Analysis of random network with respect to sensor nodes

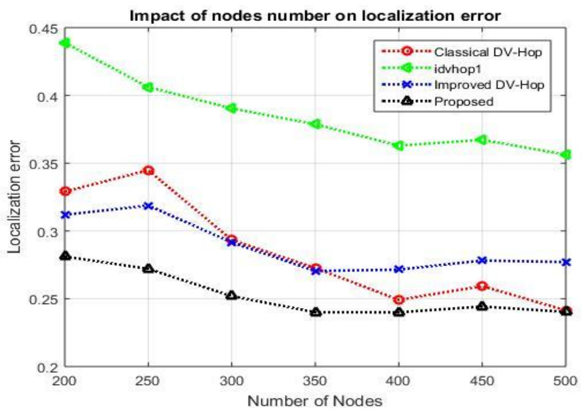

Fig. 1.3 The impact of sensor numbers on localization error

Fig.3 depicts the impact of sensor nodes on localization accuracy. Here the communication range radius is initialized to 15m, anchor percentage is 10 of total sensor nodes and sensor nodes are varied from 200 to 500 with the incremental step of 50. The increasing of sensor nodes causes higher density of network which results increased connectivity of the network. It helps to get approximate straight path between unknown node and anchor node and also collection of more information about the locality, it collectively results good localization accuracy. But at the same time, the increase of hop-count reduces sharp change in the localization accuracy.

D. Simulation graph for B-A topology

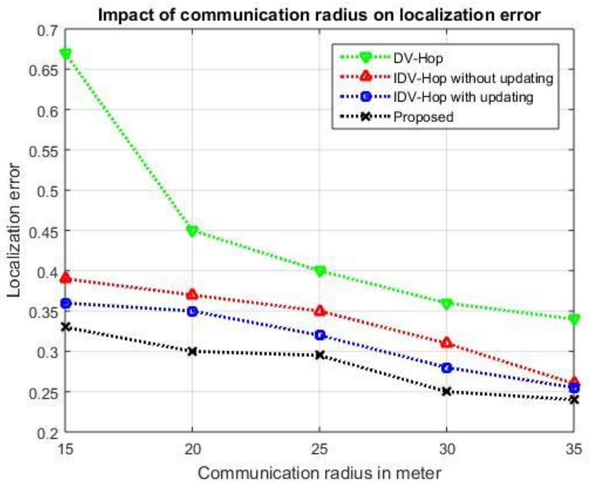

Fig. 2.1 The effect of radius(communication) in meter on average error in localization

The simulation parameters: communication range radius incremented as 15m, 20m, 25m, 30m and 35m. Total sensor nodes are equal to 200 numbers and anchor node is 20. This type of complex topology network is mainly used to reduce the probability of failure and hence to maintain healthy WSN. From the graph it is clear that the proposed work gives good result while increasing the communication range radius.

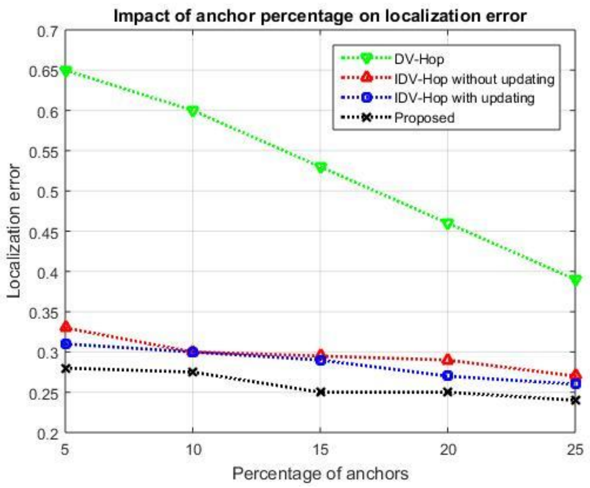

Fig. 2.2 The effect of known sensor percentage on localization error

Here the simulation values are communication range radius is 30m, 200 numbers of sensor nodes and the anchor percentage is varied as 5%, 10%, 15%, 20% and 25% of total sensor nodes. At 5% anchor node, the classical dv-hop shows large localization error and while increasing the percentage of anchor sensor nodes the proposed algorithm shows comparatively good position accuracy for (x, y) co-ordinates of unknown nodes.

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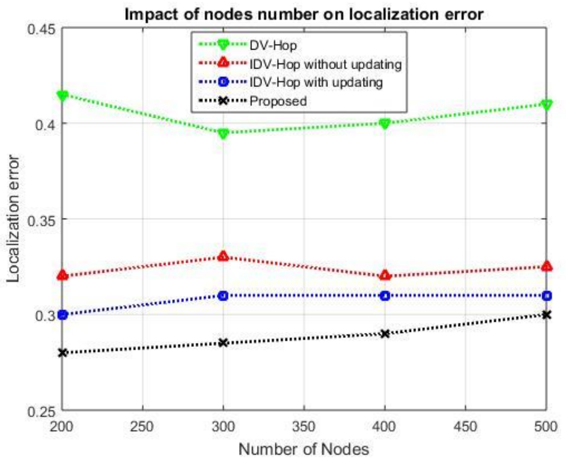

Fig. 2.3 The effect of sensor(nodes) numbers on localization error

Simulation parameters: Sensor communication range radius is 30m, anchor sensor node percentage is 10 and sensor nodes varied from 200 to 500 with the step of 50. From the graph, it is clear that the value for localization error is not regular because of the irregularity nature of BA network.

From the Fig.2.1, Fig.2 and Fig.2.3 the complex BA network shows comparatively good values for (x, y) co-ordinates of unknown nodes.

E. Simulation output for Small World Topology Network

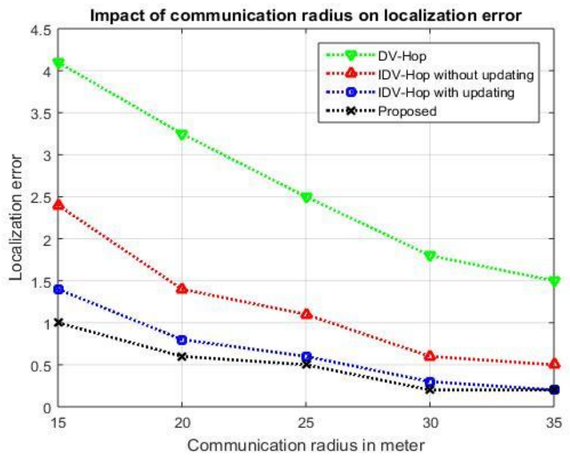

Fig. 3.1 The effect radius(communication) in meter on localization error

This type of complex topology network is mainly used to increase the life time of network by creating shortcut path in the network topology. In this simulation the communication range radius of sensor node varied as 15m, 20m, 25m, 30m and 35m, the total number of sensor node used is 200 and the number of anchor node is 20. The graph shows the error value for localization is reduced with communication range radius of sensor nodes for all the algorithms. Due to the complex nature of topology the initial value for localization error is larger than 1.35.While increasing the connectivity of sensor nodes in the network, the error value of localization decreased when the communication range radius of sensor node increases.

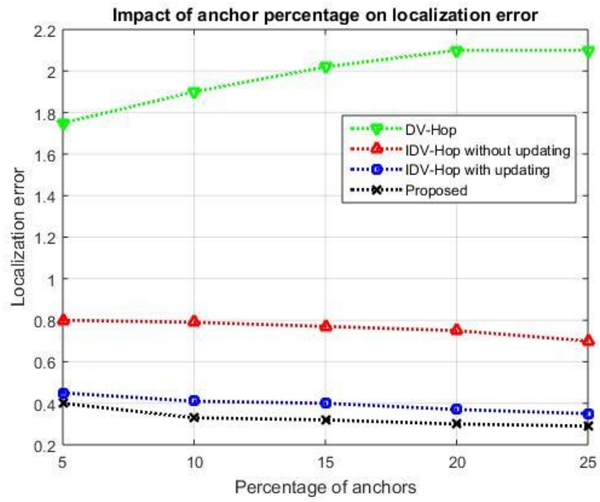

Fig. 3.2 The effect of known sensor nodes percentage on average error in localization

The above simulation output is generated by changing anchor node percentage from 5 to 25, distributing 200 sensor nodes in 100mx100m area and communication range radius to 30m. The values in plot indicates that the values of (x, y) co-ordinates of unknown nodes gives comparatively good result for proposed algorithm.

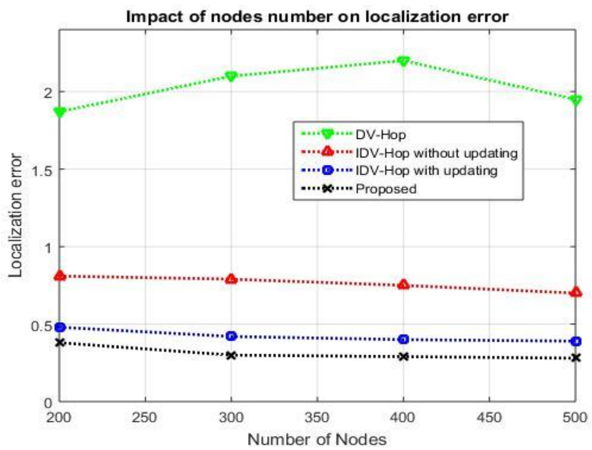

Fig.3.3 The effect of localization error with respect to nodes number

In output shown in fig. above, the number of sensor nodes varied from 200 to 250 numbers, other simulation variables are communication range radius which is set to 30m and anchor sensor node percentage is 10 of total sensor nodes distributed in the simulation area of 100mx100m. From the plot it can be clear that the localization error of introduced algorithm is low when compared to classical dv-hop technic.

V.CONCLUSION

Aiming to reduce error in localization of WSN, an improved dv-hop technique is designed by concentrating error occurred in average-hop-size calculated during the second phase of classical dv-hop design. The average-hop-value is refined by using different mathematical methods like minimum mean square error method, error factor calculated between actual and estimated distance of anchor sensor nodes, dynamic weight coefficient and finally 2D hyperbolic method.

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In the second stage the accuracy in localization is refined after calculating the (x, y) co-ordinates of unknown nodes by using some geometrical methods. The proposed algorithm used in three different kinds of network models stated as random topology, BA topology and Small World topology. The simulation plot produced in all the three different topologies by varying communication range radius, anchor sensor node percentage and number of sensor nodes shows that the proposed design gives valuable result when comparing with classical dv-hop algorithm.

Future addition of this design may try to reduce the overhead on computational process. In this design, the mobility of anchor sensor nodes on accuracy of localization is not examined. Another change may have on localization in 3D area and energy efficient design.

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