An Improved Localization Scheme Based on DV-Hop for Large-Scale Wireless Sensor Networks

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Abstract —Wireless Sensor Networks (WSNs) have revolutionized the world of distributed systems and enabled many new applications. And, measurement data or information exchanges happened in WSNs without location information are meaningless. It is extremely urgent to establish and maintain low cost and high efficient localization schemes for real-time large-scale surveillance systems. In this work, an improved DV-hop (Distance Vector-hop) based localization scheme IDV-hop (improved DV-hop) embedded in WLS (weighted least square) method is proposed for the purpose of surrounding surveillance, object localization for early warning, rescue operations and restructuring plan *et al*. Two critical parameters, correction coefficient k_c and weighted coefficient $w_{s,i}$, are introduced into IDV-hop scheme to improve location performance. And then, NS-2 simulations demonstrate that analysis results match well with simulation results. Besides, performance comparisons of IDV-hop scheme with other DV-hop based schemes are also proposed. Analysis and comparison results show that localization delay and accuracy of IDV-hop is improved largely relative to other schemes, especially for higher node density.

Index Terms—Localization, range-free, improved DV-hop scheme, WLS, WSNs

I. Introduction

WSNs play more and more decisive roles in various aspects such as environmental and habitat monitoring, precision agriculture, animal tracking, disaster rescue and almost touch upon all aspects of our life. Besides energy efficiency requirements in WSNs that withdraw energy from batteries, much other network information such as sensor or event location, executing time etc. needs to be obtained to satisfy actual requirements of many real-time applications. In many applications, measurement data or information exchanges happened in WSNs without location information are meaningless. For example, locations of exchanged messages must be known in environmental monitoring applications for bush fire surveillance, water quality monitoring or precision agriculture. Moreover, sensor positions can also help to facilitate the network with an overall point of view, such as routing or connectivity for WSNs. Therefore, localization has become a fundamental element in WSNs.

Depending on whether absolute range measurements are used or not, localization schemes can be roughly classified into two categories [1]: range based and range-free based. Range-based algorithms measure the exact distance or angle of pending localization nodes adopting techniques including TOA (time of arrival) [2], TDOA (time difference of arrival) [3], RSSI (received signal strength indicator) [4] or AOA (angle of arrival) [5]. TOA technology is commonly used as a means of obtaining range information via signal propagation time, and with two types. One is one-way propagation time measurements and the other is roundtrip propagation time measurements. Simplicity, high precision are the outstanding features for sensor localization using TOA scheme. However, there are some inferiorities for TOA scheme, such as time and hardware consuming for synchronization, and easily affected by noises etc. The most basic localization system to use TOA techniques is GPS (Global Positioning System). TDOA scheme can obtain range information via arrival time differences of messages, which can be proposed without strict time synchronizing. Time differences of localization messages may be time differences of arriving at two different receivers for one message, and also be time differences of arriving at one receiver for two different types of messages, radio propagation and ultrasound propagation for example. Like TOA technology, TDOA also relies on extensive hardware that is expensive and energy consuming for low-power sensor networks, and needs more anchors. To augment and complement TDOA and TOA schemes, AOA technique has been proposed that allows nodes to estimate and map relative angles between neighbors through installing the array antennas on sensor nodes. AOA scheme can get relative satisfied localization precise, but plenty of energy consumptions for power-wasting radio communications enables AOA to be infeasible in localization for WSNs. Less extra hardware, no time synchronization, RSSI scheme can translate received signal strength into distance estimates adopting either theoretical or empirical models, and this make it the most popular range-free localization schemes. But, adopting RF (Radio Frequency) system, problems suchlike multi-path fading, background interference, and

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irregular signal propagation characteristics make range estimates inaccurate.

Acknowledging that the cost of hardware required by range-based solutions may be inappropriate in relation to the required location precision, researchers have sought alternate range-free solutions to localization problems in sensor networks. The typical range-free algorithms [6] include Centroid [7], CPE (Convex Position Estimation) [8], APIT (Approximate Point in Triangle) [9] and DV-hop [10]. Centroid scheme was firstly proposed by Bulusu *et al*. in [11], which is a localization scheme based on network connectivity. Anchors broadcast a beacon containing their positions and ID information to neighbors. Unknown node can obtain its coordinates by presenting the centroid of these anchors after received beacons exceeding the preset threshold, or receiving time exceeding some time. Lots of anchors are required in centroid scheme to provide location information for obtaining accurate centroid point, and higher localization precision. Point-to-point communication connections between nodes can be attributed to geometrical constraint of locations of nodes, which is the key concept of CPE algorithm. Whole network is modeled as a convex set, and node localization can be come down to the optimization design. Node locations are then obtained by a global optimization solution adopting the semi-definite programming and linear programming. APIT is an area-based range-free localization scheme, which employs a novel area-based approach to perform location estimation by isolating the environment area into triangular regions between anchors, receiving beacons contained location information. By utilizing different combinations of anchors, node reduces the size of the estimated area in which the node resides to obtain a good location estimate. Instead of broadcasting in single hop, anchors in DV-hop algorithm flood their locations throughout network maintaining a running hop-count at each node along flooding paths. Unknown nodes calculate their positions adopting trilateration or other methods.

Among range-free localization methods, DV-hop algorithm handles the case where a normal node has less than three neighbor anchors, and computation complexity is relatively low which saves lots of energy. Considering these attractive advantages of DV-hop algorithm, we prefer to DV-hop based algorithm in our sensor networks.

In our DV-hop based localization scheme, several means are proposed to improve performance of DV-hop:

Firstly, correction coefficient k_c, evaluating accuracy of distances between unknown node and anchors through distance differentiations among anchors in our uniform sensor networks, is proposed to improve precision between distances of unknown node and anchors.

Secondly, weighted coefficient $w_{S,i}$ is proposed, taking three influences into account, which are transmission range, minimum number of hops between unknown node and anchor and distances among anchors.

Thirdly, unknown node is localized itself within 2-hop network for high node density. Nodes, including anchors, can transmit localization messages in 2-hop in order to avoid plenty of collisions for adopting CSMA/CA scheme. Consequently, delay is improved largely.

Lastly, distance per hop for each anchor is participated in calculating distances between unknown nodes and anchors other than only distance per hop for the nearest anchor. And then, WLS method is adopted to improve distance calculation accuracy.

The rest of this paper is structured as follows: Section II gives a summary of related works and analysis premise of our model. An improved DV-hop IDV-hop is proposed in Section III after presenting inferiors of the original DV-hop algorithm, and several means are also presented to improve performance of DV-hop. In Section IV, validations of localization error, localization delay are presented using NS-2 simulator, and comparisons of our scheme with other DV-hop based schemes are also proposed. Finally, concluding remarks are presented in Section V.

II. Related Works

DV-hop is an attractive and low energy consumption localization scheme, which is the most general range-free localization scheme based on connectivity information between nodes. Many algorithms from DV-hop have been proposed these years. Not similar to other range-free localization schemes, DV-hop algorithm handles the case where a node has less three neighbor anchors.

Three steps, localization information exchange phase for obtaining hop counters, average hop distance computation phase for every anchor and estimated position phase using trilateration or maximum likelihood estimation method, are firstly proposed by Niculescu *et al*. in [10]. An improved DV-Hop algorithm is proposed in [12] to reduce location error accumulated over multiple hops by using a differential error correction scheme. The difference or error between estimated distance of two anchors and actual distance of these anchors is calculated, and this error can be generalized to calculate estimated error of distance between unknown node and its nearest anchor. DV-Loc algorithm in [13], uses Voronoi diagrams to limit the scope of the flooding and the error of computed positions to improve localization accuracy through improving accuracy of hop count. An Advance DV-hop localization scheme [14] adopts the hop-size of anchors, from which unknown node measures distance between anchors or between unknown node and anchors. Inherent error in estimated distance between anchor and unknown node is reduced in the third step of Advance DV-hop, and WLS method is used, in which weight factor is set as the inverse of the minimum number of hops between unknown node and anchor. And, locations are refined by using extraneous information obtained by solving mathematical equations. But, weight factor in [14] has business with minimum number of hops between unknown nodes and anchors only, not taking the hop distances among anchors and transmission range into account. And these three factors are all taken into account in our IDV-hop. A threshold is introduced in [15], which uses weighted average hop distance of anchors within hops, not all anchors in networks of original DV-hop scheme to calculate average hop distance of unknown nodes, and location results are corrected of this DV-hop based scheme. HDV-hop (Hybrid DV-hop) in [16] obtains high localization accuracy and minimizes flooding and then reduces energy consumption, in which anchors are deployed only on the perimeter of sensor network and not inside it. Because of anchors are located on the perimeter of network, unknown node can contact with anchors through two or more hops, which consumes lots of energy to establish or maintain DV-hop calculation chains. We can constrain our locations in 2-hop, no matter anchor or unknown node in IDV-hop.

Two refined localization algorithms, hyperbolic-DV-hop localization algorithm and improved weighted centroid DV-hop localization scheme (IWC-DV-hop) are proposed in [17]. Instead of taking average hop-size of the nearest anchor to unknown node, hyperbolic-DV-hop scheme chooses average hop-sizes among all anchors as average hop-size of unknown node. Quad DV-hop and other two DV-hop based schemes, iDV-hop1 and iDV-hop2, are proposed in [18] to improve the localization accuracy. Quad DV-hop formulates localization problems as bounded least squares problems, to be solved by quadratic programming. Checkout and Selected 3-Anchor DV-hop schemes are proposed in [19]. Former one adjusts position of a normal node based on its distance to the nearest neighbor anchor, in which a checkout step is added to change estimated position to a new one, a relative accuracy value for computing the distance between unknown node and each anchor. The other one chooses the best 3 anchors based on connectivity parameters. Mostly, three anchors can sufficiently localize the normal sensor, rather than involving in all available anchors in network. But, how to choose appropriate 3-anchor to improve localization accuracy requires taking network topology into account. And, iterative selecting best 3-abchor group can consume lots of energy.

Moreover, there are many measurement methods in DV-hop based localization schemes for WSNs. In the third step of original DV-hop scheme, calculation of estimated location is achieved using trilateration method or maximum likelihood estimation method. Most of the localization scheme based on DV-hop algorithm adopt these two calculation methods. But in [20], normal sensor computes hop-size based on all hop-size values it receives from anchors, instead of just taking the first received hop-size value, that is, hop-size value of the nearest anchor. So, positions of normal nodes can be calculated by using weighted least square method. As related above, Advanced DV-hop in [14] also uses WLS algorithm to calculate positions of unknown nodes. And also, hyperbolic location algorithm is used to obtain locations of normal nodes related in [17].

In this paper, an improved DV-hop (IDV-hop) scheme is proposed for real-time large-scale monitoring and localization system. At first, inferiorities of original DV-hop scheme are denoted elaborately after brought briefly about original DV-hop. Then, several means are proposed to improve performance of DV-hop according to these inferiorities. And then, localization behaviors such as error and delay are validated adopting NS-2 simulations, taking parameters describing about network into account, such as ratio of anchors (p), node density (λ) and transmission range (R) et al. Moreover, performance comparisons between IDV-hop algorithm and other DV-hop based schemes, such as ADV-hop [14], Selective-3-anchor [19], HDV-hop [16], are proposed in this paper.

III. PROPOSED SCHEME IDV-HOP

A. Original DV-Hop Scheme

First, we briefly explain the original DV-hop scheme as well as some pending improvements in this scheme.

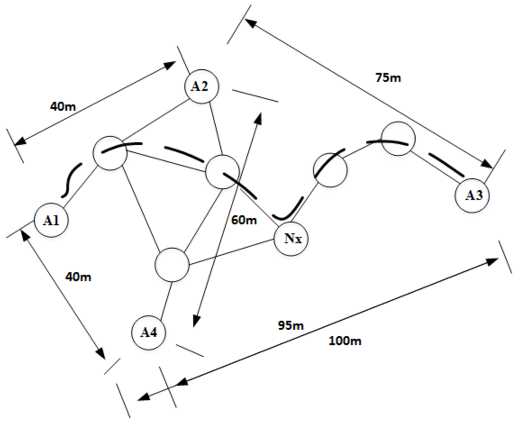

Fig. 1. The original DV-hop scheme

Step1 First, each anchor broadcasts throughout the network a message containing its position and hop count field hop_i set to 0. Hop count value hop_i increases with hop increasing during the message broadcasting, which means hop count value in the message will be incremented as soon as a node receives this message. Every node N (either anchor or normal node) records the position of A_i and initializes the value of hop_i as hop count value in the message. And, hop_i is the minimum hop count between N and A_i. If the same message is received again, node maintains hop_i, and if the received message contains a lower hop count value than it, N will update it with that lower value and relay the message. Otherwise, N will ignore the message. Through this mechanism, each node can obtain it's minimum hop count hop_i between each anchor and it separately.

Step2 Second, when an anchor A_i receives positions of other anchors as well as the minimum hop counts to other anchors, anchor A_i can calculate its average distance per hop, which is denoted as dph_i. Calculation of dph_i is shown in following (1).

$$dph_i = \frac{\sum_{j=1, j\neq i}^{M} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{j=1, j\neq i}^{M} hop_{i,j}} \qquad (1)$$

In (1), M is the number of anchors in the network, and node j refers to other anchor different from anchor i. hop_{ij} is the minimum distance between anchor i and j measured by hops. (x_i, y_i) and (x_j, y_j) refers to coordinates of anchor i and j, respectively. Once dph_i is calculated, it will be broadcasted by A_i. And then, all anchors can obtain all other anchors' dph_i, but unknown nodes can only maintain dph_i broadcasted by their nearest anchor A_{near} (either 1-hop or higher hop neighbor anchor).

When receiving hop size of A_{near}, unknown node N_x can obtain distances away each anchor (including A_{near}), which multiplies hop_{i,N_x} (its distance to A_{near} by hop count) by dph_{near}. This distance is denoted as d_{i,N_x}. Then, M distances are obtained by node N_x, which refers to d_{1,N_x}, d_{2,N_x} till d_{M,N_x}.

$$d_{i,N_x} = dph_{near} \times hop_{i,N_x} \qquad (2)$$

Note that all multiple factor dph_{near} is the same value in (2), which is average distance one hop for A_{near} from N_x.

For example, anchor A_1 is 40 meters and 2 hops away from A_2, 100 meters and 6 hops away from A_3, and 40 meters and 3 hops away from A_4 in Fig. 1. A_1 can calculate dph_1 using (1). Hence, dph_1 is equal to $(40+100+40)/(2+6+3)=16.36\text{m}$. In similar way, values of dph_2, dph_3, dph_4 as $17.5m, 16.88m, 17.73m$, respectively. Then, each anchor broadcasts it's dph_i, so other nodes including anchors receive it. N_x will maintain dph_2, the nearest neighbor anchor A_2 of N_x, and calculate distances d_{1,N_x}, d_{2,N_x}, d_{3,N_x} and d_{4,N_x} as $17.5\times3=52.5\text{m}$, $17.5\times2=35\text{m}$, $17.5\times3=52.5\text{m}$ and $17.5\times2=35\text{m}$, respectively.

Step3 Third, when receiving distances between N_x and A_i, N_x can calculate its estimated position by trilateration or other arithmetic methods as follows. (x_i, y_i) in (3) and (4) is the coordinate of anchor A_i.

$$\begin{cases} (x_1 - x)^2 + (y_1 - y)^2 = d_1^2 \\ \ldots \\ (x_M - x)^2 + (y_M - y)^2 = d_M^2 \end{cases} \qquad (3)$$

$$X = (A^T A)^{-1} A^T B \qquad (4)$$

In which,

$$A = \begin{bmatrix} 2(x_1 - x_M) & 2(y_1 - y_M) \\ \ldots & \\ 2(x_{M-1} - x_M) & 2(y_{M-1} - y_M) \end{bmatrix}$$

$$B = \begin{bmatrix} x_1^2 - x_M^2 + y_1^2 - y_M^2 + d_M^2 - d_1^2 \\ \ldots \\ x_{M-1}^2 - x_M^2 + y_{M-1}^2 - y_M^2 + d_M^2 - d_{M-1}^2 \end{bmatrix}$$

$$X = \begin{bmatrix} x \\ y \end{bmatrix}$$

B. Motivations for Improved Algorithm

DV-hop algorithm can obtain relative satisfied localization errors with less complexity and less additional hardware, to derive locations using less than 3 neighbor anchors. But, there are some defects for original DV-hop scheme, and localization performance do not come up to our expectations.

First, hop_i can be incremented with message spreading if it's received hop count is less than former maintained one in step 1. Hop count is incremented so long as the message is broadcasted once, no matter if next node is within transmission range or not, no matter if node density is high or not. This leads to over-estimate hop count value if node density is relatively high, and subsequently average hop distance is underestimated. For example, hop count between A_3 and A_1 is 6, and geometrical distance between them is 100 meters, while hop count between A_3 and A_4 is 5, and geometrical distance between them is 95 meters. If hop count is increased with broadcasting, real distance between and is underestimated.

Secondly, it cannot decide to select which anchor to calculate dph_i if there are several anchors with the same hop away from unknown node. For example, node N_x has two 2-hop neighbor anchors A_2 and A_4 in Fig.1, and it cannot decide which one it maintains dph_2 or dph_4. And, N_x maintains only dph_{near} to calculate distances between anchors and it, which is not so proper.

Thirdly, network connectivity also plays an important role in DV-hop localization scheme. Distance between two nodes (either anchor or normal node) is represented by hops, rather than by geometrical distance. Network connectivity exerts a tremendous influence on hop distance, which means hop distance can bring about greater inaccuracy if network connectivity is relatively low. For example, hop distance between anchor and anchor is 3 hops through broadcasting in Fig. 1, but the geometrical distance is only 40 meters in fact, almost one hop away from each other.

Finally, unknown node can obtain its location through trilateration, which need three known anchors at least, no matter where anchors located. Hops can be enlarged if anchor density is relatively low, which brings about dph_{near} being lower than actual one. And, unknown node tries to seek farther anchors through two or more hop relay transmission, which can bring about a plenty of unnecessary energy consumption.

C. IDV-Hop Scheme

Several means are proposed to improve inferiors above related in Section I. Firstly, correction coefficient k_c is proposed to evaluate accuracy of distances between unknown node and anchors through the distance differentiations among anchors in our uniform sensor networks.

Secondly, weighted coefficient $w_{S,i}$, a comprehensive and precise illustrating parameter, is proposed to present the influence of transmission range, minimum number of hops between unknown node and anchor, distances among anchors, other than presenting only one parameter of distances between unknown node and anchors more.

Thirdly, unknown node is localized itself in 2-hop network for high node density. Nodes, including anchors, can transmit localization messages in 2-hop in order to avoid plenty of collisions for adopting CSMA/CA scheme. Consequently, delay is improved largely.

Lastly, distance per hop for each node is participated in calculating distances between unknown node and anchors. And then, WLS method is adopted to improve distance calculation accuracy. Now, IDV-hop is presented in following.

Step 1 Localization request

First, hop_i is initialized to 0. After network initialization completed, each node can be aware which hop it is belong to. Also, all nodes in the network can establish their one-hop neighbor list and update this list at every localization slot. As localization request phase starts up, unknown node N_x in its 1-hop circle can confirm its 1-hop anchor neighbors A_{1i} (anchor nodes in 1-hop) just in 1-hop circle. And then, N_x sends a *RL* (Request Localization) frame to anchors A_{1i}, and *RL* frame contains all 1-hop neighbors. If the number of A_{1i} is greater than or equal to 3, node can directly go to execute DV-hop scheme as initial DV-hop scheme. If the number of is less than 3, it need spread its *RL* frame to 2-hop neighbors. And also, 2-hop neighbors including anchor neighbors A_{2i} (anchor nodes in 2-hop) are added to this frame. If the sum of A_{1i} and A_{2i} is greater than or equal to 3, localization scheme can be promoted. Otherwise, this localization can be failure.

Step 2 Hop information exchange

Second, localization request phase finished, anchor A_{1i} broadcasts a *HIE* (Hop information exchange) frame containing location of A_{1i}, ID of A_{1i} and also hop_i. There are three cases for obtaining hop_i. The first one is that the number of anchor nodes in the intersection area for 1-hop neighbors of N_x and 1-hop neighbors of A_{1i} is greater than or equal to 3, each hop_i is set 1, and sum $\sum hop_{ij}\,(\mathrm{i} \neq \mathrm{j})$ is set to the number of other anchor nodes (case 1). If anchor number in this intersection area is less than 3, hop_i is set to 1 if other anchors in 1-hop of A_{1i}, and set to 2 if other anchors in 2-hop of A_{1i}. Sum is $(N_{A_{1i}} + 2N_{A_{2i}} - 1)$ (case 2). Of course, if anchor number in 1-hop of N_x is less than 3, IDV-hop can expand to anchors A_{2i} in 2-hop of N_x, and this case is the same as second one (case 3).

$$\sum hop_{ij}\,(\mathrm{i} \neq \mathrm{j}) = \begin{cases} N_{A_{1i}} - 1 & \text{case1} \\ N_{A_{1i}} + 2N_{A_{2i}} - 1 & \text{case2,3} \end{cases} \tag{5}$$

$$\begin{cases} N_{A_{1i}} = 4p\lambda \int_{d/2}^{2R} \sqrt{4R^2 - x^2}\,dx \\ N_{A_{2i}} = p\lambda\pi R^2 - 4p\lambda \int_{d/2}^{2R} \sqrt{4R^2 - x^2}\,dx - \\ \qquad 2p\lambda\left(\int_{(3R^2-d^2)/2d}^{R} \sqrt{R^2 - x^2}\,dx - \right. \\ \qquad \left. \int_{d+(3R^2-d^2)/2d}^{2R} \sqrt{4R^2 - x^2}\,dx\right) \end{cases}$$

where $N_{A_{1i}}$ and $N_{A_{2i}}$ refers to the number of neighbor anchors in 1-hop circle and the number of neighbor anchors in 2-hop ring, respectively.

Step 3 Distance calculations

Distance per hop dph_i can be obtained as follows. Once dph_i is calculated, it will be broadcasted by A_{1i} or A_{2i}, and then, all anchors can obtain dph_i as (6).

$$dph_i = \frac{\sum_{i \neq j} \sqrt{(x_i - x_j)^2 + (\mathrm{y}_i - \mathrm{y}_j)^2}}{\sum_{i \neq j} hop_{ij}} \tag{6}$$

Unknown node N_x maintains each dph_i broadcasted by each anchor, not similar to dph_{near} in original DV-hop, calculates distance away from each anchor $dph_{N_x,i}$ in (7). In which, dph_{1i} and dph_{2i} refers to average distance per hop of A_{1i} and A_{2i}, respectively.

$$dph_{N_x,i} = \begin{cases} dph_{1i} & case1 \\ 2 * dph_{2i} & case2,3 \end{cases} \tag{7}$$

Step 4 Location calculations

Correction coefficient k_c is introduced in IDV-hop to improve accuracy of distance $dph_{N_x,i}$ in (8).

$$k_c = \frac{dph_{est}^{i,j} - dph_{true}^{i,j}}{dph_{true}^{i,j}}\Big|_{i \neq j} \tag{8}$$

In (8), actual distance $dph_{true}^{i,j}$ of each anchor is calculated using the geometric method involving actual coordinates, $dph_{true}^{i,j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$ and estimation distance $dph_{est}^{i,j}$ is calculated through Eq.6. In similar way, distance $dph_{true}^{N_x,i}$ of N_x and anchors is calculated using (9). Actual distance $dph_{true}^{N_x,i}$ and estimation distance $dph_{est}^{N_x,i}$ is calculated as the same way, for the difference between $dph_{true}^{N_x,i}$ and $dph_{est}^{N_x,i}$ is considered as the similar to the difference between $dph_{true}^{i,j}$ and $dph_{est}^{i,j}$ for our uniform networks.

$$dph_{true}^{S,i} = \frac{dph_{est}^{S,i}}{1+k_c} \tag{9}$$

Coordinate of N_x is denoted as (x, y), location of N_x is then calculated by using following (10-11), in which $dph_{true}^{N_x,i}$ is presented as a simple form d_i . And n is the number of anchors, i.e. the simple form for N_{A_i} .

$$\left.\begin{array}{l}\sqrt{(x-x_1)^2+(y-y_1)^2}=d_1\\ \sqrt{(x-x_2)^2+(y-y_2)^2}=d_2\\ \dots\\ \sqrt{(x-x_n)^2+(y-y_n)^2}=d_n\end{array}\right\} \tag{10}$$

$$\left.\begin{array}{l}\sqrt{(x-x_1)^2+(y-y_1)^2}-\sqrt{(x-x_n)^2+(y-y_n)^2}=d_1-d_n\\ \sqrt{(x-x_2)^2+(y-y_2)^2}-\sqrt{(x-x_n)^2+(y-y_n)^2}=d_2-d_n\\ \dots\\ \sqrt{(x-x_{n-1})^2+(y-y_{n-1})^2}-\sqrt{(x-x_n)^2+(y-y_n)^2}=d_{n-1}-d_n\end{array}\right\} \tag{11}$$

Squaring both sides and simplifying (11), we can obtain (12) as the same as [14].

$$\left.\begin{array}{l}-2x(x_1+x_n)-2y(y_1+y_n)+2(x^2+y^2)\\ =d_1{}^2+d_n{}^2-(x_1^2+y_1^2+x_n^2+y_n^2)\\ -2x(x_2+x_n)-2y(y_2+y_n)+2(x^2+y^2)\\ =d_2{}^2+d_n{}^2-(x_2^2+y_2^2+x_n^2+y_n^2)\\ \dots\\ -2x(x_{n-1}+x_n)-2y(y_{n-1}+y_n)+2(x^2+y^2)\\ =d_{n-1}{}^2+d_n{}^2-(x_{n-1}^2+y_{n-1}^2+x_n^2+y_n^2)\end{array}\right\} \tag{12}$$

$$Q=\begin{bmatrix}-2x(x_1+x_n) & -2y(y_1+y_n) & 1\\ -2x(x_2+x_n) & -2y(y_2+y_n) & 1\\ \dots & & \\ -2x(x_{n-1}+x_n) & -2y(y_{n-1}+y_n) & 1\end{bmatrix}$$

$$H=\begin{bmatrix}d_1{}^2+d_n{}^2-(x_1^2+y_1^2+x_n^2+y_n^2)\\ d_2{}^2+d_n{}^2-(x_2^2+y_2^2+x_n^2+y_n^2)\\ \dots\\ d_{n-1}{}^2+d_n{}^2-(x_{n-1}^2+y_{n-1}^2+x_n^2+y_n^2)\end{bmatrix}$$

$$Z=\begin{bmatrix}x\\ y\\ k\end{bmatrix}$$

$$QZ=H \tag{13}$$

WLS algorithm is adopted to solve the coordinates of IDV-hop scheme, to improve location accuracy. In WLS method, unknown parameters in (14) is presented as:

$$Z=(Q'W'WQ)^{-1}Q'W'WH \tag{14}$$

In which, W is weighted matrix which is presented the influence of distance between anchors and unknown node, transmission range and distances between an anchor and other anchors.

$$W=\begin{bmatrix}w_{N_x,1} & 0 & \dots & 0\\ 0 & w_{N_x,2} & \dots & 0\\ \dots & & & \\ 0 & 0 & \dots & w_{N_x,n-1}\end{bmatrix} \tag{15}$$

Weight $w_{N_x,i}$ in (15) is taken as the inverse of $hop_{N_x,i}$ between each anchor and N_x in [14, 20]. Not only as [14], [20], weight $w_{N_x,i}$ should also take R and h_{ij} into account in this work, which is demonstrated as (16).

$$w_{S,i}=\frac{1}{hop_{S,i}}\frac{1}{N_{A_i}-1}\sum_{k=1}^{N_{A_i}-1}(1-\frac{hop_{ik}{}^2}{R^2}) \tag{16}$$

In (16), N_{A_i} is presented as (5). Weight values influenced by these three parameters play important roles on the localization accuracy, which will be analyzed through simulations in Section 4 later.

IV. PERFORMANCE VALIDATIONS

Extensive simulations are presented in this section to validate accuracy of evaluated metrics for localization error and delay using NS-2 simulator, based on analyses of different parameters such as anchors' ratio, node density etc. NS-2 is a popular discrete-event simulator which was originally designed for wired networks and has been subsequently extended to support wireless simulations. And also, performance comparisons between IDV-hop scheme and other DV-hop based schemes, such as ADV-hop [14], Selective-3-anchor [19], HDV-hop [16], are proposed to validate some accuracy and delay superiority of this time-critical scheme IDV-hop.

As shown in Fig. 2, high anchor ratio means that anchors in 1-hop of N_x are enough for localizing unknown node. And also, with anchor ratio p increasing, weight $w_{N_x,i}$ of each anchor decreases, each distance between anchor and unknown node can only play an insignificant role on localization accuracy. Moreover, with anchor number increasing, accuracy of k_c increases, consequently location for unknown node has more accuracy shown in Eq. 8 and Eq. 16. Transmission range R (R denoted in all Figs.) plays an important role on localization error. With R increasing, error decreases. And R increases to a higher value such as $R=40m$, error increases as shown Fig. 3 for nodes including anchors need more time to identify their 1-hop or 2-hop neighbors. Seen from Fig. 2 and Fig. 3, analysis results are consistent with simulation results, which is abbreviates as "ana" and "sim" in all figures, respectively.

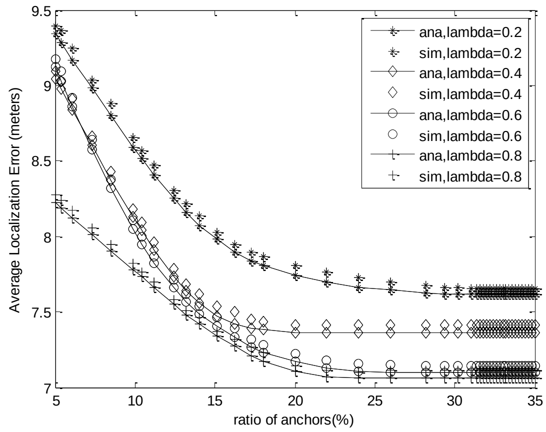

Fig. 2. Localization error

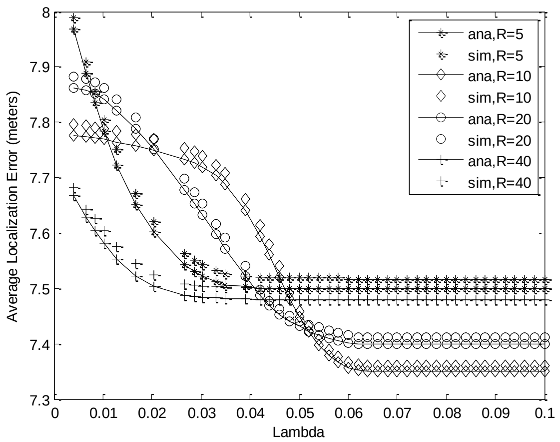

Fig. 3. Localization error based on λ .

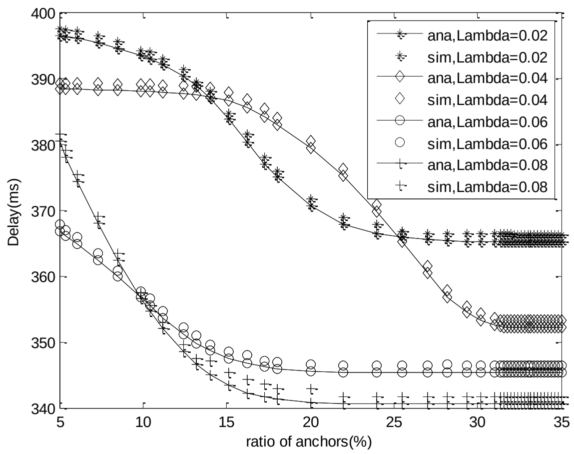

Fig. 4. Localization delay.

If node density λ (Lambda denoted in all Figs.) increases, more nodes including anchors will access the channel simultaneously, more collisions are brought out for adopting CSMA/CA transmission scheme, leading to retransmissions increasing. Consequently, localization delay behavior will become inferior shown in Fig. 4.

Transmission range R also plays an important role on localization delay shown in Fig. 5. When R increases to $R = 40m$, delay increases sharply.

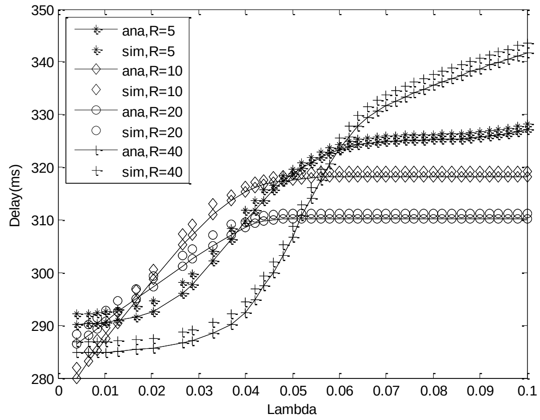

Fig. 5. Localization delay based on λ

IDV-hop shows better localization behaviors with the variety of node density shown in Figs.6-7, comparing to ADV-hop scheme [14], HDV-hop scheme [16] and Selective-3-anchor scheme [19]. As related above, ADV-hop scheme reduces localization errors using WLS method and other improved methods, taking the weight factor as the inverse of the minimum number of hop count between unknown node and each anchor. In fact, weight factor $w_{N_x,i}$ has also business with the number of anchors, transmission range and hop counts among anchors. These three factors are taken into account in our IDV-hop scheme, which bring out higher accuracy.

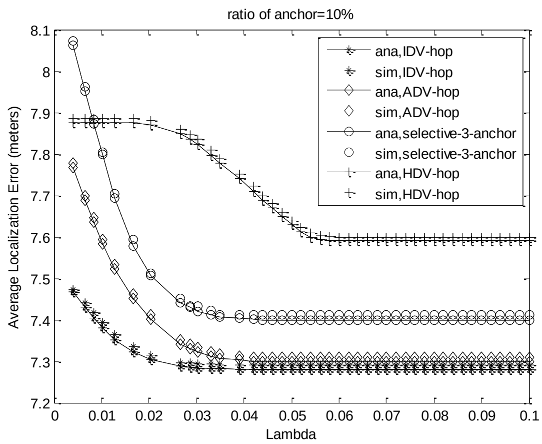

Fig. 6 Localization error comparison based on λ

Three estimated distance values away from three different anchors are sufficient for unknown node to calculate its location related in selective 3-anchor DV-hop (selective-3-anchor). Based on the first two steps of original DV-hop, unknown node can obtain a group of candidates to calculate its location. Then, the best 3-anchor group is chosen to establish estimated position using iterative method, which consumes lots of energy for the computational complexity, and it is unsuitable for wireless sensor networks and is also incomparable to IDV-hop scheme.

HDV-hop is suitable for localizing events in hostile environments, which anchors are deployed on the perimeters of the networks rather than scattering them inside the hostile terrain. Consequently, unknown node which localizes itself will transmit the localized messages, including hop count, hop size and the distance of this unknown node and each anchor, traversing two or more hops. This consumes plenty of energy which is intractable to normal monitoring sensor networks. Anchors are located randomly in circle plane, according to a two-dimensional Poisson distribution with a density of λ in IDV-hop. Node is localized within 1-hop or 2-hop, which can present higher localization accuracy and save much transmission energy.

Nodes including anchors increasing, unknown node can execute IDV-hop in 2-hop sensor networks, which increases accuracy of hop count hop size and distance of unknown node and each anchor shown in Fig. 6. And also, localization delay comparisons show that localization delay presents prior behaviors, especially for higher node density shown in Fig. 7. With nodes increasing, more anchors are located in the transmission range of unknown node in IDV-hop. And unknown node can request to be localized in 1-hop, localizing itself in 1-hop, which can save lots of time. Distance differences, among anchors or between anchors and unknown node, can be reduced to small values. The value of anchor ratio is assigned to 10% for the performance comparisons in this paper, taking the localization characteristics of all four schemes into account.

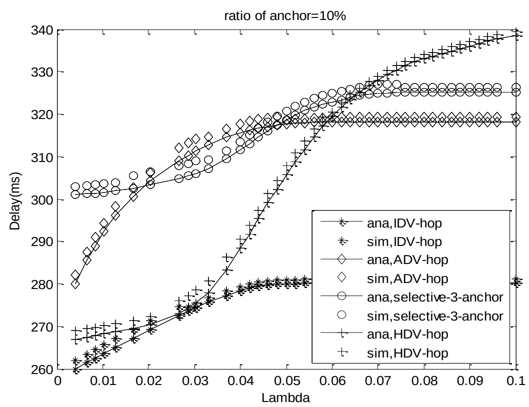

Fig. 7. Localization delay comparison based on λ

V. CONCLUSIONS

In this paper, we have presented a range-free localization scheme IDV-hop in WSNs embedded in WLS method. At first, inferiorities of original DV-hop scheme are denoted elaborately after brought briefly about original DV-hop. Then, an improved localization scheme embedded in WLS method is proposed based on these inferiorities, and two critical parameters, correction coefficient k_c and weighted coefficient $w_{S,i}$, are introduced into this scheme to improve localization performance. And then, performance of error and delay is validated. Moreover, performance comparisons between IDV-hop other DV-hop based schemes are proposed.

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