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Approach to Improving Localization Systems in Networks of Wireless Sensors

Mitta Nourreddine[1], El Gouri Rachid[2] and Laamari Hlou[3]
[1,2,3]Laboratory of Electrical Engineering & Energy Systems, Faculty of Science, Ibntofail University, Kenitra, Morocco
[1]noureddine_mitta@yahoo.fr

***Abstract*—In the context of wireless sensor networks, the localization technique "*range-free*" is more efficient with respect to the principle "*range-based*". Therefore, we focused on it. To enable each mobile or normal node to choose its own localization algorithm, we proposed a mechanism adapted by splitting normal nodes in two categories: the first category nodes have at least three neighboring anchors, while nodes the second category have less than three neighboring anchors. For first normal category nodes, we proposed a new algorithm "*Recovery center* ". For second normal nodes, we proposed two new algorithms "*Extensible DV-hop*" and "*Anchor selection DV-hop*" to simulate and evaluate the performance of our three new algorithms in the context of network protocol, we have taken care to provide two related protocols: "*Extensible & Anchor selection DV-hop protocol*" and "*First-Category protocol*". Subsequently, we combined these two protocols for our "*Accommodation range-free localization protocol*". Based on our protocol, using *WSNet*, we simulated different algorithms "*range-free*" in the context of sensor networks comply with *IEEE 802.15.4*. The results were presented and analyzed in terms of accuracy of location, network capacity, node mobility, and theirs synchronization.**

***Index Terms*—Wireless Sensor Networks, Localization, Range-Free, Algorithm and Protocol**

I. INTRODUCTION

In recent years, wireless sensor networks are central to the research activities of the scientific community, particularly given the vast potential applications such as medical care, smart homes, or environmental monitoring. For these applications, the location of mobile communication equipments is an important issue.

The existing localization algorithms can be classified into two categories "*range-based*" and "*range-free*".

The "*range-based*" localization principle is to accurately measure the distance or angle between two nodes on a network. Several technologies allow this measure, we have for example: the *RSSI* (*Received Signal Strength Indicator*) [1], the *TO* (*Time of arrival*) [2], *TDOA* (*Time Difference of Arrival*) [3]-[4] or *AOA* (*Angle of Arrival*) [5]. After this measurement, the position can then be obtained simply by triangulation. The "*range-based*" location has two major drawbacks. The first is related to the additional hardware required for the measurement. These hardware measurements consume more energy and increase the cost of the solution. The other drawback is based on the accuracy of the measurements can vary several parameters related to the network environment: the humidity, electromagnetic noise, and propagation (multi-path fading) indoors in particular.

The "*range-free*" location avoids these two great disadvantages. Generally, nodes, fixed or mobile, whose position is known, are called anchors. With other nodes to determine a position or normal nodes are called normal nodes. To estimate their positions, the normal nodes first collect information network connectivity as well as the position of anchors, then calculates their own positions. To the principle

TABLE I. COMPARISON BETWEEN RANGE-BASED AND RANGE-FREE SCHEMES

"Range-based"	"Rang-free"
Higher precision	Lower precision
Need additional ranging devices	Don't need additional devices
Easily affected by multi-path fading and noise	More robust

TABLE II. COMPARISON OF RANGE-BASED LOCALIZATION

Range-based Methods		Advantages		Disadvantages	
RSSI	Direct Calculation	No additional hardware	Scalable, Low overhead	Low accuracy	
	Fingerprinting		Better accuracy	Non-flexible, memory cost	
	Direct Calculation	Better accuracy than RSSI	Low overhead	Strict synchronization	Ultra-high timing requirement, expensive hardware
	Two-way Ranging		No rigid synchronization		
AOA		Low timing / synchronization requirement, Better accuracy than RSSI		Hardware constraints, affected by multipath fading and noise	

TABLE III. COMPARISON OF RANGE-FREE LOCALIZATION

Range-free Algorithms		Advantages	Disadvantages	
Centroid		Low overhead	Low accuracy	A normal node needs at least 3 neighbor anchors.
CPE	original CPE	Good accuracy	Centralized, high overhead	
	simplified CPE	Low overhead	Low accuracy	
APIT		No ideal radio assumption	High power, RSSI needed	
DV-hop		No restrict on the number of neighbor anchors	Low accuracy, big overhead (network) (the overheads of DDV-hop and Robust DV-hop are even higher than DV-hop and Self-adaptive DV-hop)	
DDV-hop				
Self-adaptive DV-hop				
Robust DV-hop				

"*range-based*" technology "*range-free*" is thus more profitable, because there is no need for extra hardware for measurement and evaluation of distance. So it can adapt to any type of wireless transmission. Consequently, we focused our work on "*range-free*" approaches.

In the literature, many "*range-free*" localization algorithm-ms have been proposed. Among them "*Centroid* " and "*CPE*" (*Convex Position Estimation*) originally proposed by Doherty [6], require normal nodes with at least three neighboring anchors jump, while *DV-hop* (*Distance Vector-Hop*) origin-nally proposed by Niculescu [7] does not impose this restrict-tion. The *APIT* algorithm [8]-[9] is not frequently used as anchors shall have high power transmitters, and unstable *RSSI* information is required. However, the algorithms "*range-free*" are not precise enough. In addition, the algorithms in the literature are generally considered off-context without taking into account the protocol aspects. Our goal is to provide algorithms but also the associated protocols to improve the positional accuracy of this type of "*range-free*" method.

This paper is organized as follows. Section I provides an overview of the work on the research field for us. Section II introduces our proposed new algorithms. Section III presents the new associated protocols that we offer. Section IV presents and analyzes the results of simulations that we conducted to validate our proposals. Finally we conclude and present our work prospects.

II. State Of Art

In this section, the work near to our research problem are studied and compared, some of them, such as "*Centroid*" and "*CPE*", are very simple, but require that the normal nodes have at least three neighboring anchors. Other works, such as "*DV-hop*" can be used for all normal nodes, even those who don't have three anchors in range, but generate more network traffic.

"*Centroid*" and "*CPE*" are two typical algorithms based on "*range-free*" methods. We assume that around the normal node N_x, there is m neighboring anchors A_1, A_2 ... A_m, whose positions are respectively (x_1, y_1) (x_2, y_2). . . (x_m, y_m). It is also assumed that all nodes have the same radio range. This assumption is of course purely theoretical but commonly accepted by the scientific community that contributes to this research. The principle of "*Centroid*" is as follows: anchors periodically broadcast their position; N_x then receives the position of anchors and compute its position as the estimated average of neighboring anchor position. The estimated posi-tion is calculated as:

$$x_{cen} = (\sum_{i=1}^{m} x_i)/m,\ y_{cen} = (\sum_{i=1}^{m} y_i)/m \quad (1)$$

In "*CPE*" (*Convex Position Estimation*) algorithm, the estimated normal nodes positions are calculated as the result of an optimization problem. Since the optimization process is too complicated for nodes whose computing power is limited, the original algorithm is centralized "*CPE*": a more powerful server takes all the calculations and radio broadcasts the results to normal nodes. Due to this principle, the original "*CPE*" algorithm is not very flexible because highly centralized.

A simplified and distributed version "*CPE*" algorithm was proposed. The principle is to define the estimated rectangle (*ER*) which limit the overlap zone ranges A_1, A_2 ... A_m . After, the center of the estimated rectangle is considered the estimated position of N_x. Coordinates are calculated as follows:

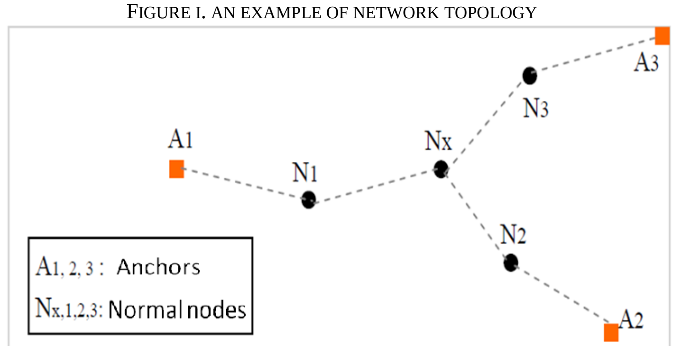
$$x_{ER} = \frac{\min_i x_i + \max_i x_i}{2},\ y_{ER} = \frac{\min_i y_i + \max_i y_i}{2}. \quad (2)$$

"*Centroid*" and "*Simplified CPE*" has two advantages: a thin network load and low computational complexity. But the precisions are not very good. For example based on the "*Centroid*" algorithm, the experiments in [10] show that the localization error is about 1.83 meters, when the radio range of sensor nodes is 8.94 meters.

The above algorithms work only for normal nodes with at least three neighboring anchors. However, if the density of anchors is not high enough in the network, some normal nodes can sometimes find themselves with less than 3 nearby an-chors. In this case, it is possible to use algorithms based on "*DV-hop*".

In "*DV-hop*" the system can locate normal nodes when they are less than three nearby anchors, while "*Centroid*" and "*CPE*" cannot solve this case. Unfortunately, this comes at the cost of more traffic and more numerous and complex calculations. In Fig. 1, although the normal N_x node has only one neighbor to anchor its radio range, N_x can use "*DV-hop*" to locate. "*DV-hop*" consists of the following three steps:

Figure I. An example of network topology



Step 1: First, each anchor A_i diffuse through the network a frame containing its position and the number of hops initialized to *0*. This value increases for the dissemination of this frame. This means that as soon as the frame is received by a node the value of the number of hops in the frame will be incremented when the relay. At the first reception of the frame, each *N* (normal or anchor) node records the position of A_i, and initializes hop_i as the value of the number of jumps in the frame. Here hop_i is the minimum number of hops between *N* and A_i. After, if *N* receives the same frame, *N* maintains the hop_i field: if the received frame contains a value less than the number of hops hop_i, *N* update hop_i with this value and will relay this frame, if the value of the number of hops in the frame is greater than hop_i, *N* will ignore this frame. Through

this mechanism, all nodes in the network can obtain the minimum number of hops to each anchor.

Step 2: When each anchor A_i received the positions of the other anchors and the number of minimum jumps to other anchors, A_i can calculate the average jump distance noted dph_i. Details on the calculation of dph_i can be found in [6]. Thereafter, dph_i will be broadcast to all nodes of the network by A_i.

Step 3: When receiving dph_i the normal N_x node multiplies $hop_{i,Nx}$ (the number of jumps A_i) by dph_i and N_x can get the distance to each anchor A_i, denoted $d_{i,Nx}$. Here $i \in \{1, 2 ... m_d\}$, where m_d is the total number of anchors in the system. Then each normal node can calculate its estimated $N_{DV\text{-}hop}$ by triangulation position. Details on the calculation of $N_{DV\text{-}Hop}$ can be found in [6].

Although the "*DV-Hop*" algorithm can locate the normal nodes with less than three neighboring anchors, its location accuracy needs to be improved as well. Thus, many algorithms based on "*DV-hop*" have been proposed in recent years by the scientific community.

DDV- hop: this algorithm changes the Step 2 and Step 3 of the "*DV-hop*" algorithm. In step 2 of "*DDV-hop*", each anchor A_i broadcasts not only its distance-per-hop dph_i through the network, but diffuses also differential error of dph_i. The definition and calculation of the differential error can be found in [11]. In step 3, "*DDV-hop*" and "*DV-hop*" differ from each other by calculating the estimated difference between a normal node N_x and each anchor A_i distance. In the "*DDV-hop*" algorithm, N_x uses its own distance jumping noted dph_{Nx} to replace dph_i the distance jumps A_i). Here dph_{Nx} is obtained as the weighted sum of the distances of all anchors jump.

The weights are determined by the differential error distances by jumping anchors.

Self- adaptive DV-hop: this algorithm consists of two complementary methods. As the second method needs information RSSI type, generally we consider the first method of "S*elf-adaptive DV-hop*". This algorithm induces the same network as "*DV-hop*" charge, but modify softly step 3. In step 3, when a normal node N_x calculates the estimated distance to A_i. *N* uses its own distance jumping noted dph_{adj} to replace dph_i (jump distance A_i). dph_{adj} is obtained by the weighted sum of the distances obtained by hopping all anchors . In this algorithm, when calculating dph_{adj}, the weighting factor dph_i is base decided on the number of hops between N_x and A_i. More there is hops between N_x and A_i, smaller is the value assigned to weighting factor dph_i.

Robust DV-hop: the Robust DV-hop (*RDV-hop*) algorithm is proposed in [12]. It differs from the two above algorithms, because it replaces dph_i (jump distance A_i). "*RDV-hop*" sets the value of distance-by-hop between N_x and A_i noted $dph_{i,k}$.

In calculations $dph_{i,k}$ the weighting factor of $dph_{i,k}$ is the maximum factor if N_x is a node on the shortest path between A_i and A_k.

All the above algorithms based on "*DV-hop*" using a weighting method to determine a jump distance for each normal node. All times to determine a more precise distance jump, additional information is sometimes necessary such as the differential error in "*DDV-hop*" and number of hops to all anchors in "*Robust DV-hop*". The dissemination of this additional information increases the network traffic. It should also be noted that the simulation results of these algorithms studied and presented above are not convincing because the distributions of nodes in the simulations are particularly and specific, instead than random distributions. Motivated by these findings, our goal was to get a better accuracy without increasing the load on the network; we have proposed new and more efficient algorithms.

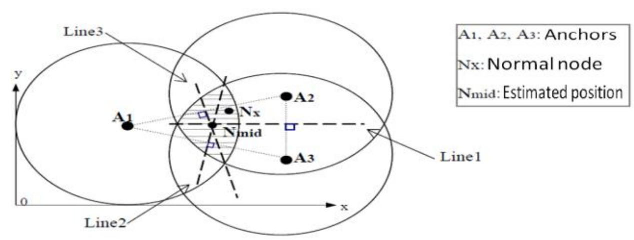
III. PROPOSED NEW ALGORITHMS RANGE-FREE

Following the previous analysis of the typical algorithms associated with the method "*range-free*" when a normal node has at least three neighboring anchors, it can locate using algorithms such as "*Centroid*" or "*CPE*" (Mostly the simplified version of "*CPE*" is used as non-centralized and less restrictive). However, when normal within three anchors neighboring node, it must use algorithms based on "*DV-hop*".

IV. A NEW "RANGE-FREE" ALGORITHM FOR NODES IN THE "FIRST-CATEGORY"

For normal "*First-Category*" nodes "*Centroid*" and "*CPE*" are methods commonly used because of their low computational cost and low network traffic generated. However, their precise location is not very efficient. Our new method "*Recovery center*" will be able to achieve better accuracy. Its principle is to try to find the center of the overlap region of adjacent radio cells anchors.

FIGURE II. "*RECOVERY CENTER*" IN CASE OF THREE NEIGHBORING ANCHORS



First, we studied the case of a normal node has only three neighboring anchors. As shown in Fig. II, around the normal node N_x, there is in this case a study three neighboring anchor A_1, A_2 and A_3. N_x is therefore in the area of overlap of cells A_1, A_2 and A_3. This figure also shows how to calculate the center of the overlap region. Right A_2A_3 connects anchors A_2 and A_3. Bisects the right A_2A_3 is "Line1". By symmetry, Line1 through the center of the overlap zone. The lines A_1 and A_3 A_1 A_2 have their bisector, respectively Line2 and Line3.

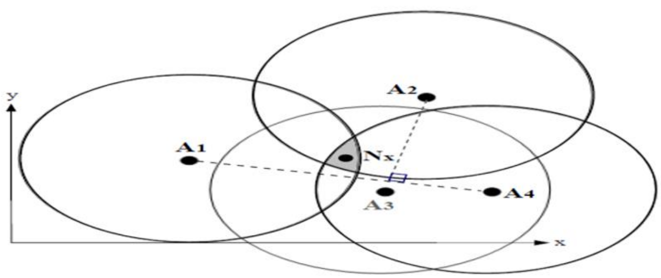
Each bisector traverses the center of the overlap zone. So, the intersection of the three bisectors N_{mid} noted can be considered the center of the overlap region. Indeed, so as to calculate the position of the intersection N_{mid} only two bisectors are necessary, for example, Line1 and Line2. If the coordinates of the three anchors A_1 A_2 A_3 are respectively (x_1, y_1), (x_2, y_2) and (x_3, y_3), the position of N_{mid} can be finally calculated as:

$$\begin{cases} x_{mid} = \dfrac{(x_1^2 - x_2^2)(y_3 - y_1) + (x_1^2 - x_3^2)(y_1 - y_2) + (y_1 - y_2)(y_2 - y_3)(y_3 - y_1)}{2[y_1(x_2 - x_3) + y_2(x_3 - x_1) + y_3(x_1 - x_2)]} \\ y_{mid} = \dfrac{(y_1^2 - y_2^2)(x_3 - x_1) + (y_1^2 - y_3^2)(x_1 - x_2) + (x_1 - x_2)(x_2 - x_3)(x_3 - x_1)}{2[x_1(y_2 - y_3) + x_2(y_3 - y_1) + x_3(y_1 - y_2)]} \end{cases} \quad (3)$$

We note that there is a condition for the derivation above: if the three neighboring anchors N_x form an acute triangle where all angles are less than 90 degrees. However, if the three neighboring anchors form a triangle rectangle it or obtuse triangle, calculating N_{mid} is simple: this time, N is the center of the longest side of the triangle.

Thereafter, we studied the case of a normal over three neighboring anchors around the normal node N_x and $m > 3$. We found the cells overlap area of all m anchors obtained mainly by three anchors. In Figure 3, we give an example of four adjacent anchors. In this figure, we can see that the cells overlap area of four anchors is actually obtained by the contribution of three anchors A_1 A_2 and A_4. These three anchors have the following characteristics: (1) two of them have the longest distance between compared to the distances between the four anchors. This is because the two most distant anchors are A_1 and A_4. (2) The third anchor is farthest from the line connecting the two anchors mentioned above. In this example, as the two most distant anchors are A_1 and A_4. Other anchors are A_2 and A_3. Compared to A_3, A_2 has a longer line distance between A_1 and A_4. And the third anchor is A_2.

FIGURE III. AN EXAMPLE WITH FOUR NEIGHBORING ANCHORS



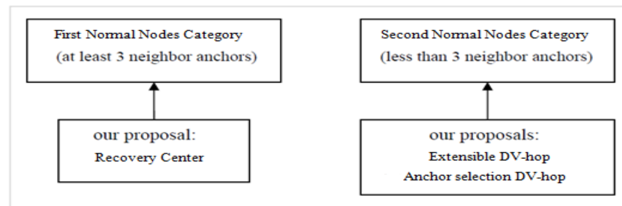
We now know how to find the three anchors which are the cells overlap area of m neighboring anchors. First, N_x calculates the distance between all pairs of two anchors. As there a m neighboring anchors, there will C^2_m total distances to calculate. Comparing these distances N_x can find two most distant anchors rated A_i and A_k. Then among all other anchors excluding A_i and A_k , N_x is the third anchor that has the longest distance to the line connecting A_i and A_k. This anchor is denoted A_j . Thus, A_i, A_j and A_k are the three anchors which are the overlapping area of all cells m anchors. Finally, N_x can calculate the center of the overlap zone cells A_i, A_j and A_k , then the node gets its estimated position.

The simulation results we have achieved with *MATLAB* show that, on average, "*Recovery center*" offers better accuracy than *Centroid* and *CPE*.

New "range-free" algorithms for nodes of "second-category":

In general, in a network, there are always some anchors and many normal nodes. Consequently, most of the normal nodes belong to "*Second-Category*" with less than three anchors nearby. The "*DV-hop*" algorithm is frequently used to locate nodes in the "*Second-Category*". However, its accuracy is not sufficient. To improve accuracy, we proposed two new algorithms "*Extensible DV-hop*" and "*Anchor selection DV-hop*".

FIGURE IV. PROPOSAL FOR CORRESPONDING CATEGORY OF NORMAL NODES



Extensible DV-HOP:

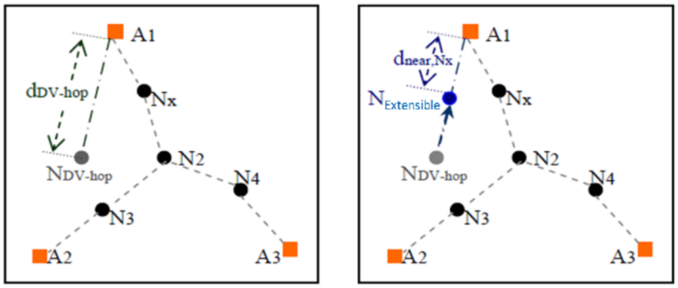
As we have seen, for normal nodes of "*Second-Category*", "*DV-hop*" is a method of "*range-free*" locating used frequently. The "*DV-hop*" key idea is to calculate the average minimum distance jump. This means that $d_{i,Nx} = hop_{i,Nx} \times dph_i$ where $d_{i,Nx}$ is the approximate distance between N_x and A_i. $hop_{i,Nx}$ is the minimum number of hops between N_x and A_i. dhp_I is the approximate average distance jump on A_i. Here i appertain to the set [$1,2$, ... m], if the total number is m.

As $d_{i,Nx}$ is a fundamental parameter for the position calculation of the normal node N_x , it has a considerable influence on the "*DV-hop*" accuracy. We note distance between N_x and A_i: $d_{i,NxTrue}$ and the difference between $d_{i,Nx}$ and $d_{i,NxTrue}$: $\Delta_{di,Nx}$. Naturally $\Delta d_{i,Nx}$ influences directly the "*DV-hop*" accuracy. We note the difference between dph_i and the real value Δdph_i , and we obtain $d_{i,Nx} = hop_{i,Nx} \times dph_i$. So when $hop_{i,Nx}$ increases Δdph_i increase also and "*DV-hop*" accuracy becomes lower. If A_{near} is the nearest all possible anchors N_x, correspondingly hop_{near} anchor, N_x is the smallest value. $d_{near,Nx}$ is the smallest possible distance error . Finally, $\Delta d_{near,\mathrm{Nx}}$ compared to the other anchor , the evaluation of the distance between and N_x and A_{near} denoted $d_{near,Nx}$ is more accurate . Based on this deduction, our "*Extensible DV-hop*" algorithm tries to make the most of $d_{near,Nx}$, which is relatively the most reliable value .

In Fig. IV, we illustrate the "*Extensible DV-hop*" principle. Our method adds only "*DV-hop*" step. Using "*DV-hop*", normal N_x node obtains its estimated position noted $N_{DV\text{-}hop}$ with coordinates (x', y'). Then N_x calculates the distance between $N_{DV\text{-}hop}$ and A_{near} denoted $D_{DV\text{-}hop}$. Note that N_x assessed its distance A_{near} denoted $d_{near,Nx}$. Thereafter, N_x executes step "*Extensible*".

The purpose of this step is to move the estimated position of $N_{DV\text{-}hop}$ to a new position $N_{Extensible}$ whose distance of A_{near} is $d_{near,Nx}$. To achieve this goal, the easiest and quickest way is to move the position along the line connecting $N_{DV\text{-}hop}$ and A_{near}. $N_{Extensible}$ is on this line, the distance between $N_{DV\text{-}hop}$ and A_{near} is $d_{near,Nx}$.

FIGURE IV. "*EXTENSIBLE DV-HOP*" PRINCIPLE



(a) *DV-hop* (b) *Extensible DV-hop*

In section IV, using *MATLAB*, we performed several simulations with different scenarios where nodes are randomly distributed in space location. The results show that our "*Extensible DV-hop*" algorithm reaches higher than the "*DV-hop*" algorithm accuracy 15%.

Anchor Selection DV-HOP:

Using the estimated difference between the normal "*Extensible DV-hop*" node and its nearest anchor, adjust the distance of localization of "*DV-hop*". Although "*Extensible DV-hop*" adds only simple "*DV-hop*" stage, the improvement in accuracy is not very remarkable. Thus, we propose another new algorithm "*Anchor selection DV-hop*", which can get better accuracy at the cost of a significant increase in computational complexity. The basic principle of this algorithm is as follows: the normal node selects all three potential anchors to form "*anchor groups*", then it calculates the estimated using the "*anchor groups*" positions. Finally, depending on the relationship between the estimated positions and connectivity, the normal node selects the most accurate position.

Consider a network with m_d anchors A_1, A_2 ... A_{md} using the "*DV-hop*" algorithm, a normal node N_x can calculate its estimated $N_{DV\text{-}hop}$ based on the estimated distances to the anchors position. And the accuracy of these estimates a significant influence on "*DV-hop*" distances.

In fact, instead of using all m_d distance estimated three distances are sufficient to N_x to calculate its position. For example we can use $d_{i,Nx}$, $d_{j,Nx}$, $d_{k,Nx}$, which are the three estimated distances between N_x and three anchors A_i, A_j , A_k . Then, based on the *MLE* method (*Maximun Likelihood Estimation*) we can get a "*third-anchor estimated position*" N_x, denoted as $N_{<i,j,k,>}$.

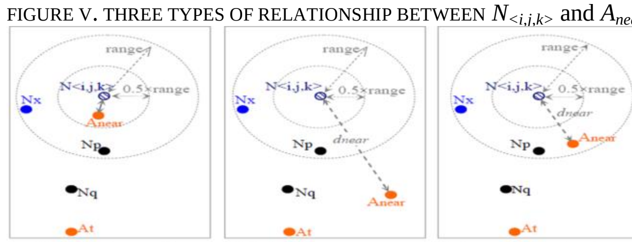
The principle of "*Anchor selection DV-hop*" is to select the most accurate "*third-anchor estimated position*" Here, the selection criterion is connectivity. In the "*DV-hop*" algorithm, connectivity N_x is defined as the minimum number of hops between N and anchors. For example, if in a network, there m_d anchors in total, and if the minimum number of hops between N_x and each anchor A_i is $hop_{i,\ Nx}$, then the N_x connectivity is [$hop_{1\ ,\ Nx}$, $hop_{2\ ,\ Nx}$ .. . $hop_{md\ ,\ Nx}$]. Smaller the difference in connectivity between nodes, smaller the distance between them. According to this relationship, "*third-anchor estimated position*" with the most similar to N_x connectivity should be as close to N_x. Thus, the basic principle of our "*Anchor selection DV-hop*" algorithm is to choose the "*third-anchor estimated position*" that the connectivity most similar to N_x.

However, the connectivity of "*third-anchor estimated position*" $N_{<i,j,k>}$ is still unknown. Therefore, we propose the following method to calculate the number of hops between $N_{<i,j,k>}$ and each anchor, noted $hop_{<i,j,k>,\ t}$. The distance between $N_{<i,j,k>}$ and each anchor A_t : $d_{<i,j,k>,t}$. . Thus, if N_x knows the jump distance between $N_{<I,j,k>}$ and A_t noted $dph_{<i,j,k>,\ t}$, then N_x can calculate the number of hops between $N_{<i,j,k>}$ and A_t as $hop_{<i,\ j,k>,\ t} = d_{<I,j,k>,\ t} / dph_{<i,\ j,k>,\ t}$. It must therefore to find how to estimate $dph_{<i,j,k>,\ t}$.

In fact, N_x knows only distances by hopping each anchor: dph_1, dph_2 , ... dph_{md} including distance jump A_t noted dph_t . Thus, we must estimate $dph_{<i,j,k>\ ,\ t}$ based on dph_1 , dph_2 , ... dph_{md} . For this purpose, three types of relationship between $N_{<i,j,k>}$ and nearest anchor A_{near} are considered , depending on their distance. In the first case, the distance between $N_{<i,j,k>}$ and A_{near} is so small that we can use the distance by jumping on A_{near} (denoted dph_{near}) as an approximation of $dph_{<i,j,k>,\ t}$. In contrast, in the second case, the distance between N and A is so large that we cannot use that as dph_t approximation of $dph_{<i,j,k>,\ t}$. The third case is between the two cases above, therefore, the value of $dph_{<i,j,k>,\ t}$ can be defined as the average dph_{near} and dph_t . These three cases are shown in Fig. V.

The procedure of "*Anchor selection DV-hop*" algorithm is as follows. The first and second steps are the same as "*DV-hop*". In the third step, N_x first calculates its "*third-anchor estimated position*" and N_x calculates the connectivity of each "*third-anchor estimated position*". Finally, N_x chooses the best "*third-anchor estimated position*" which has the most similar connectivity with him.

FIGURE V. THREE TYPES OF RELATIONSHIP BETWEEN $N_{<i,j,k>}$ and A_{near}



5(a) d_{near}<range/2 5(b) d_{near}>range 5(c) range/2< d_{near}<range

The results of the simulations carried out and presented in section IV show that our *algorithm* "*Anchor selection DV-hop*" reaches a precision better than several other existing algorithms. Improved accuracy can be 20 % to 57%, compared with different algorithms and different scenarios.

V. Proposal For New Protocols

When checking our three new algorithms presented above, we found that most existing algorithms have been studied by the scientific community using only algorithmic simulators such as *MATLAB*. Problems with networks and protocols influences are generally neglected as the collision of frames at the MAC layer and node synchronization. We then proposed two protocols: "*DV-hop protocol*" and "*First-Category protocol*". Subsequently, we combined these two protocols for our "*Accommodation range-free localization protocol*".

DV-HOP Protocol:

Our "*DV-hop protocol*" can be used to implement algorithms based on "*DV-hop*", including "*Extensible DV-hop*" and "*Anchor selection DV-hop*". In "*DV-hop protocol*", we defined formats adapted frames, a new "*E-CSMA/CA*" access method to improve the performance of classical MAC "*non-slotted CSMA/CA*" layer and adapted several parameters to complete each step of the protocol.

Two frame formats are available for the first two stages of "*DV-hop protocol*". They are in accordance with the general format defined in the IEEE 802.15.4 standard. In step 1, each anchor A_i broadcasts on the network a frame "*frame_posi*" so that all normal nodes (in anchors and normal nodes) can be knows position A_i and the minimum number of jumps A_i . In step 2, A_i diffuses through the network a frame "*frame_dphi*" which contains the average distance jump on A_i.

We also proposed a new "*E-CSMA/CA*" access method to reduce collisions of frames. Collisions can occur when anchors broadcast their frames simultaneously. When each anchor broadcasts a frame A_i according to the principle of "*non-slotted CSMA/CA*", A_i first waits a random short period and if the channel is still free, the frame is sent immediately. In the standard, the short period is randomly selected from the eight values: $0, t_{bo}$, $t_{bo} \times 2, 7 \times t_{bo}$, t_{bo} where is the *back-off* period . According to the IEEE 802.15.4 standard, if the data rate is 250kbps, t_{bo} duration is 320 ms, and the maximum value of this random period of 7x320µs= 2.24ms . With such a waiting period as short as, simultaneously broadcast over the network, collisions occur too frequently.

The solution we propose to reduce collisions is to add another longer random time before "*CSMA/CA*". Thus, the probability of collision is reduced. At the beginning of step 1 of the "*DV-hop protocol*", each anchor A_i waits for a random period denoted t_{wpi}. Then, A_i performs "*non slotted CSMA/CA*" and sends its "*frame_posi*" frame. Similarly, at the beginning of step 2, A_i waits for a random period denoted t_{wdi}. Then, A_i performs the classic "*CSM /CA*" and sends its "*frame_dphi*" frame.

To complete each step of the "*DV-hop protocol*", we proposed some specific parameters. First, "*num_wait_pos*" is close to the value in step 1. As a node has not received the positions number of anchors, it cannot complete step 1. Also $T^0_i + t_{s1}$ have been proposed as the time to complete step 1. Even if a node has not yet received at least "*num_wait_pos*" positions anchors must complete step 1 if that period expires. In addition, "*num_wait_dph*" is the number of distances jump to finalize step 2. Finally, we proposed the same way $T^0_i\ t_{s1} + t_{s2}$ is the time to complete step 2. We will present and analyze the simulation results with the simulator *WSNet* on "*DV-hop protocol*" in Section IV.

First-Category Protocol:

Our "*First-Category protocol*" can be used to implement algorithms such as "*Centroid*", "*CPE*" and "*Recovery center*". It includes three steps; the basic principle of “*First category protocol*“ is presented below.

First, N_x broadcasts a frame to its neighbors for a location request. This frame is denoted "*frame_req*". During the broadcast of "*frame_req*" our method "*E-CSMA/CA*" should be used to reduce collisions, because many normal nodes can simultaneously be willing to send their frames.

Second, if a nearby anchor N receives the request for the N_x, this anchor sends its position to N_x. Here "*E-CSMA/CA*" is also recommended to reduce collisions because it can be large anchors around N_x (6 for example). Simultaneously, all the anchors receive "*frame_req*" and are ready to send their positions.

Finally, if for a period t_{RECV}, N_x positions received from at least three neighboring anchors, N_x can calculate its position using algorithms such as "*Centroid*", "*CPE*" and "*Recovery center*". We will present and analyze the simulation results on “*First category protocol*” section IV.

Accommodation Range-Free Localization Protocol:

The two protocols presented above have each their advantages and disadvantages. The "*First-Category protocol*" is simple, but it requires normal at least three anchors neighboring nodes. "*DV-hop*" protocol can be used by all normal nodes, but it induces a significant network load. To take advantage of these two protocols, the combination is considered our "*Accommodation range-free localization protocol*".

The choice of "*First-Category protocol*" and "*DV-hop protocol*" is decided by the network administrator. We need to set a threshold for the ratio of anchors, noted RA_{thresh}. If the ratio is lower anchors RA_{thresh}, the administrator chooses "*DV-hop protocol*" for most normal nodes have less than three anchors nearby. But, if the ratio is greater than anchors RA_{thresh} to avoid high traffic, "*First-Category protocol*" should be used in preference.

RA_{thresh} value is chosen by the administrator based on the maximum traffic that can accept and knowledge on the number of anchors in the network. A small value indicates that RA_{thresh} may accept a lower network load. But the value of RA_{thresh} cannot be too low because in this because then many normal nodes with less than three neighboring anchors cannot be located.

VI. Simulations And Evaluations

To assess the accuracy of the algorithms "*range-free*" simulations were performed using *MATLAB*. Note that the distribution of nodes has an important influence on the accuracy of the algorithms. In general, the accuracy of our "*Recovery Center*" algorithm is 15 % higher than the "*Centroid*" and "*CPE*" algorithms. Our "*Extensible DV-hop algorithm*" has a positional accuracy of about 15 % better than "*DV-hop*". However, our algorithm "*Anchor selection DV-hop*" is 45 % more accurate than "*DV-hop*".

TABLE IV. SCENARIO PARAMETERS FOR "*FIRST-CATEGORY*" ALGORITHMS

Scenario Parameters	Values
Node Radio Range	20 meters
Simulation Area	40m×40m Square Area
Radio Propagation	Ideal, no pathloss, no interference
Real position of N_x	(20m, 20m)
Number of Anchors *"m"*	to be decided in specific scenario
Random Simulation Number	to be decided in specific scenario

TABLE V. LOCATION ERROR (% RADIO RANGE): MAXIMUM, AVERAGE, AND MINIMUM

Number of Anchors /	Algorithms	Centroid	CPE	Recovery Center	
				Direct	Simplified
3	Maximum	63%	62%	62%	
	Average	28%	26%	19%	
	Minimum	0.6%	0	0	
4	Maximum	54%	55%	53%	53%
	Average	25%	24%	18%	15%
	Minimum	0.5%	0	0.5%	0
5	Maximum	46%	48%	42%	42%
	Average	17%	17%	14%	13%
	Minimum	0.4%	0	0.5%	0
6	Maximum	44%	42%	42%	39%
	Average	18%	17%	14%	10%
	Minimum	0.6%	0	0.4%	0
7	Maximum	39%	36%	36%	39%
	Average	15%	16%	13%	11%
	Minimum	0.6%	0	0.6%	0
8	Maximum	38%	36%	35%	35%
	Average	13%	13%	11%	9%
	Minimum	0.3%	0	0.05%	0

FIGURE VII. AVERAGE LOCATION ERROR FOR SCENARIO 4

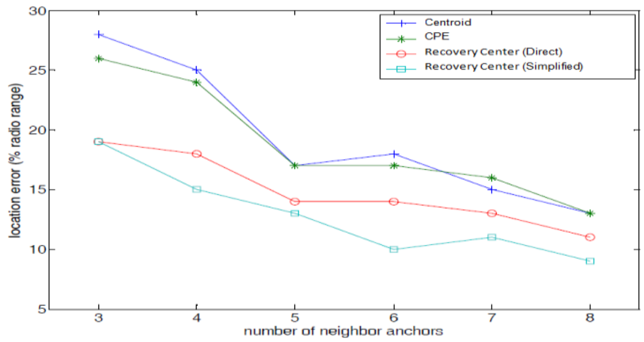


FIGURE VIII. MAXIMUM AND MINIMUM LOCATION ERRORS OF "*CENTROID*" AND "*SIMPLIFIED RECOVERY CENTER*"

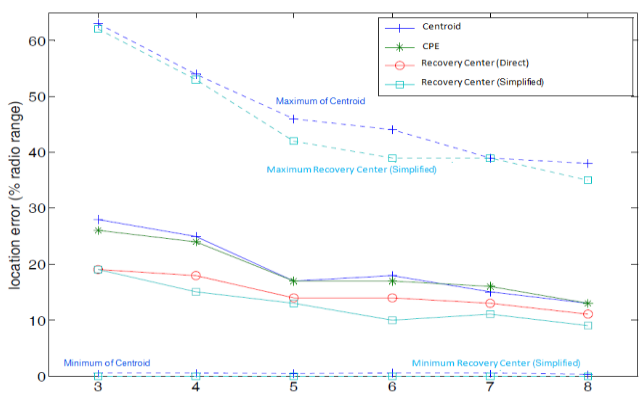


FIGURE IX. PROBABILITY OF LOCATION ERROR (3 NEIGHBORS ANCHORS)

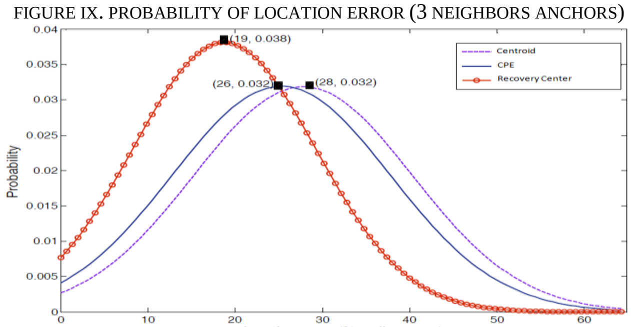


TABLE VI. SCENARIO PARAMETERS FOR "*SECOND-CATEGORY*" ALGORITHMS

Scenario Parameters	Values
Node Radio Range	20 meters
Simulation Area	40mx40m Square Area
Radio Propagation	Ideal, no pathloss, no interference
Real position of N_x	(20m, 20m)
Number of Anchors "*m*"	to be decided in specific scenario
Random Simulation Number	to be decided in specific scenario

TABLE VII. LOCATION ERROR (%RADIO RANGE) MAXIMUM, AVERAGE, AND MINIMUM FOR SEVERAL SCENARIOS

Anchors Ratio	DV-hop			DDV-hop			Self-adaptive DV-hop			Robust DV-hop			Extensible DV-hop			Anchor selection DV-hop		
5%	327	71	5	319	73	6	319	73	6	305	67	5	220	61	4	---------		
10%	284	65	5	301	67	6	295	67	6	277	58	5	209	55	3	163	43	2
20%	195	62	4	203	64	5	202	63	6	186	55	4	157	53	3	114	40	2
30%	125	56	3	138	59	3	138	57	3	113	51	2	130	48	3	83	36	1
40%	162	58	3	177	62	3	177	60	3	150	52	2	143	50	3	108	37	1
50%	151	57	3	159	61	4	154	59	3	133	50	2	136	49	2	89	35	1
60%	176	58	3	184	62	3	187	60	3	143	52	3	125	50	2	83	35	1
70%	164	57	2	163	60	3	163	58	2	138	52	2	112	50	2	81	36	1
80%	138	56	1	157	62	3	156	58	3	124	52	2	109	49	2	81	34	1
90%	137	56	2	136	58	2	133	57	3	111	50	2	105	49	2	79	33	1

FIGURE X. PROBABILITY OF LOCATION ERROR IN CASE OF ANCHORS RATIO 10%

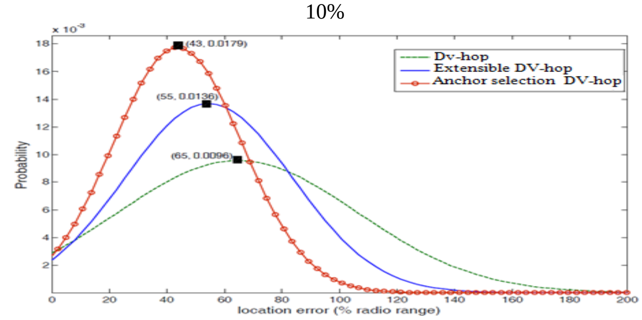


FIGURE XI AVERAGE LOCATION ERROR OF ALGORITHMS FOR "*SECOND-CATEGORY*" NODES

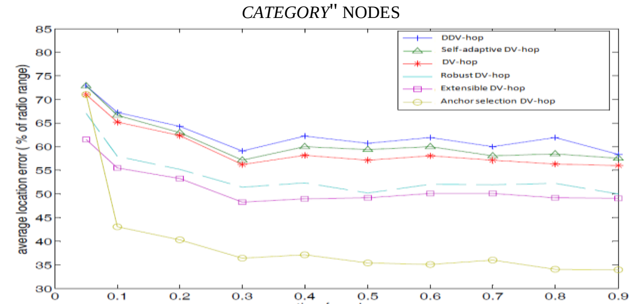
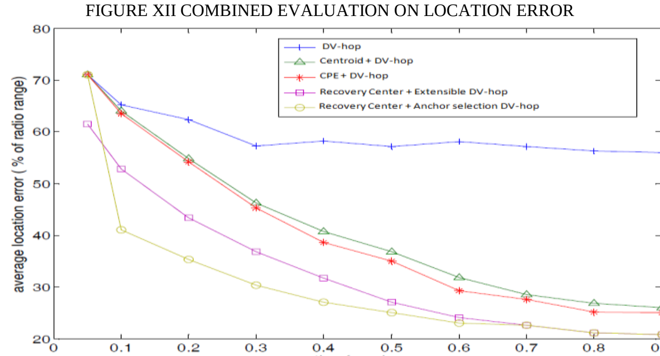


FIGURE XII COMBINED EVALUATION ON LOCATION ERROR



We also evaluated the theoretical computational complexity of algorithms. "*Centroid*" and "*CPE*" have low complexity of order $O(m)$, while "*Recovery Center*" lead one as high as $O(m^2)$ complexity. The "*DV-hop*" and "*Extensible DV-hop*" complexity remains to O level (m_d), but "*Anchor selection DV-hop*" leads to a higher order of $O(m^3_D)$ complexity. Here, m is the number of neighboring anchors around a normal node, while m_d is the number of all anchors in the network.

TABLE VIII. COMPARISON OF MATHEMATICAL ANALYSIS AND SIMULATION RESULTS

	Theoretical Results	Simulation Results (calculation time in millisecond)
Centroid	$O(m)$	0.12
CPE	$O(m)$	0.08
Recovery Center	$O(m^2)$	1.37
DV-hop	$O(m_d)$	1.41
Extensible DV-hop	$O(m_d)$	1.49
Anchor selection DV-hop	$O(m_d{}^4)$	435.16

Our protocols have been modeled using the simulator *WSNet* in the context of sensor networks comply with IEEE 802.15.4 . The results show that overall; our new algorithms associated with proper protocols are more accurate than the conventional algorithms. Compared to the network load, protocols based on "*DV-hop*" are much heavier than the "*First-Category protocol*" because "*DV-hop*" requires global broadcast in the network. Given the mobility of nodes, the influence on precision based on "*DV-hop*" protocols is more important than the "*First-Category protocols*", because "*DV-hop*" requires a longer period for global broadcasts. Finally, we also showed that the timing of the various stages is not necessary for our protocols.

VII. Conclusion And Outlook

In the context of wireless sensor networks, the "*range-free*" localization technique is more efficient with respect to the principle of "*range-based*". Consequently, we have focused our work for this paper on "*range-free*" techniques.

To enable each normal node to choose its own localization algorithm following the surrounding topology, we propose a suitable mechanism separating normal nodes into two categories: the nodes in the first category have at least three neighboring anchors, while nodes in the second category have less than three neighboring anchors.

For normal first category nodes, we proposed a new algorithm "*Recovery Center*", which seeks to find the center of the overlapping area of adjacent radio cells anchors. The simulation results by *MATLAB* show that, on average, "*Recovery Center*" offers better accuracy than "*Centroid*" and "*CPE*".

For normal Tier 2 nodes, we proposed two new algorithms "*Extensible DV-hop*" and "*Anchor selection DV-hop*". The simulation results show that "*Extensible DV-hop*" has a positional accuracy of about 15% higher than "*DV-hop*", while the accuracy of "*Anchor selection DV-hop*" is 45% better than "*DV-hop*".

When checking by simulating our three new algorithms, we noticed that most of the existing algorithms are studied using only algorithmic simulators such as *MATLAB*, problems with networks and protocols influences were generally neglected as the collision frames and synchronization nodes. We have taken care to provide two related protocols: "*DV-hop protocol*" and " *First-Category protocol*". Subsequently, we combined these two protocols for our "*Accommodation range-free localization protocol*". For these protocols, we defined formats adapted frames, and a new access method "*E-CSMA/CA*" to improve the performance of classical MAC "*non-slotted CSMA/CA*" layer. On the one hand, our "*DV-hop protocol*" can be used to implement algorithms based on "*DV-hop*", including "*Extensible DV-hop*" and "*Anchor selection DV-hop*". On the other hand, our "*First-Category protocol*" can be used to implement algorithms such as "*Centroid*", "*CPE*" and "*Recovery center*".

Based on our protocol, using *WSNet*, we simulated different algorithms "*range-free*" in the context of sensor networks comply with IEEE 802.15.4. The results were presented and analyzed in terms of the accuracy of the location, network load, node mobility, and synchronize them.

In perspective, we propose to study the performance of algorithms using a real model radio layer. It would also be interesting to combine algorithms "*range-based*" and "*range-free*". The last question relates to perspective the implementation of our algorithms and protocols on real prototypes.

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