

# Employing Unmanned Aerial Vehicles for Localization of Sensor Nodes in Wireless Sensor Networks

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**ABSTRACT:** *Wireless sensor networks (WSNs) is emerging as a key tool for data acquisition in many applications, and localization algorithms of the sensors have a vital importance due to the intrinsic characteristics of this type of networks. The objective of this paper is to propose an algorithm of range-free localization for WSNs using an unmanned aerial vehicle (UAV) equipped with a rotary directional antenna. This algorithm, denominated as the azimuthally defined area localization algorithm (ADAL), is executed in each sensor node and is based only on the analysis of the information received from the UAV, therefore is energy efficient and contributes to extend the lifetime of the sensor network. Additionally the proposed algorithm has the advantage of being simple and economical. The simulation results show that the proposed algorithm is a practical, effective and accurate method for sensor nodes location in a WSN.*

**Keywords:** Range-free localization, Wireless sensor network, Unmanned aerial vehicle, Directional antenna

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## 1. Introduction

Nowadays there is a huge and increasing demand for information acquirement, a great amount of sensors of different domains and backgrounds are being produced, but a single sensor sometimes can only sense one specific type of physical variable (temperature, vibration, pressure, etc.). Research and development of low-power sensors, MEMS, wireless data communications and tiny embedded devices has motivated the investigations and implementations of WSNs [1].

WSNs has become in an important research focus in computer science and communications fields. The possible applications of WSNs are innumerable; they can be used in many areas, such as environmental monitoring, chemical/biological agent detector, machine monitoring, medical care, intelligent buildings, disaster prevention, inventory tracking, traffic monitoring and military surveillance, only to mention some of them. But in many applications of WSNs, the information of the physical parameter that they sense is not useful unless this information is complemented with the geographical location of the sensor, therefore nodes localization algorithms represent a paramount research topic in WSNs [2, 3].

Generally speaking, a WSN is an ad hoc network consisting of a great number of tiny, inexpensive sensors with low power transceivers and limited computing capacity, deployed in a determined zone of interest, and few more complex nodes, sometimes called anchor nodes, capable of determine its own position by any means (e.g. using a global positioning system like GPS or GLONASS).

The objective of this paper is to propose an algorithm of range-free localization for WSNs using an unmanned aerial vehicle (UAV) equipped with a rotary directional antenna. This algorithm, denominated as the azimuthally defined area localization algorithm (ADAL), is executed in each sensor node and is based only on the analysis of the information received from the UAV.

The rest of this paper is organized as follows: section II describe some localization methods in wireless sensor networks, section III point out several advantages of using a mobile agent approach in WSNs, section IV introduce previous works that use mobile beacons to localize nodes in WSNs, section V establishes the network assumptions considered for this work and

section VI offers a detailed explanation of the algorithm. The evaluation of the algorithm performance is done in section VII, and finally the conclusions and future work are stated in section VIII.

## **2. Localization Methods in WSNs**

Actually, a great number of localization algorithms for WSNs have been proposed. These algorithms can be divided into two categories: ranged-based algorithms and range-free algorithms, this classification is made according to whether it needs to know the real range between nodes or not. The ranged-based algorithms need to measure by means of additional hardware the distance or angle between each node in order to determine its geographical position. Range-free algorithms instead use the network constraints such as connectivity or anchor nodes information to estimate an estimate coordinates of the nodes [4, 5]. Localization algorithms include, but are not limited to.

### **2.1 Range-Based Localization Algorithms**

It exist several methods which are used to measure distances or angles among nodes, range-based localization techniques generally are classified as follows:

#### **Received Signal Strength Indication (RSSI)**

RSSI is a method based in the decreasing of the energy of the radio signals as they travel in space to estimate distances between emitters and receivers [6]. The propagation loss of signal is calculated by transmitted strength of beacon nodes and receiving strength of sensor nodes, and it is converted into range using existing theories and experimental data based models. With the measured distances positions of sensor nodes is estimated by means of known algorithms.

RSSI requires no additional hardware and has low power consumption. However, RSSI is easy affected by temperature, barriers, and signal propagation mode in the outdoor environment.

#### **Time of Arrival (TOA)**

In this method the localization is achieved measuring the range between the transmitter and the receiver, based on the propagation time of signals whose velocity is perfectly known [7]. It requires the distances of at least three reference nodes and the estimated position is obtained by trilateration, or maximum likelihood estimation. This technique has a good accuracy, but it requires additional hardware on each sensor node, and needs synchronization of the network.

#### **Time Difference of Arrival (TDOA)**

In this method the anchor nodes send two kinds of radio signals with different propagation velocities simultaneously, and the sensor nodes are able to calculate distances according to the variation of arrival time between these two signals. Finally the approximate locations of nodes are estimated by means of known algorithms for this purpose [8]. In this technique synchronization is not a big issue, but needs more dedicated equipments than TOA, therefore node sensors hardware is more complex.

#### **Angle of Arrival (AOA)**

Angle of Arrival is a method for determining the direction of propagation of a radio-frequency wave incident on an antenna array [9]. AOA determines the direction by measuring the time difference of arrival (TDOA) at individual elements of the array, and based in these delays the angle of arrival is calculated. Generally this TDOA measurement is made by measuring the difference in received phase at each element in the antenna array. AOA technology requires either an antenna array or several ultrasound receivers, so it increase size and power consumption of sensor nodes.

### **2.2 Range-Free Localization Algorithms**

In the range-free methods sensor nodes don't need additional equipments to measure distances or angles, therefore additional equipments are not required, additionally range-free localization techniques are less susceptible to be influenced by the environmental conditions, and although its accuracy is not as high as the range-based methods, it can satisfy the requirements of the majority of applications of WSNs [10]. These types of techniques generally are classified as follows:

#### **Distance Vector-Hop (DV-Hop)**

The DV-Hop algorithm basically consists of three phases; the first step of this algorithm is the flooding of the position of beacon nodes through the network. At this stage sensor nodes and beacon nodes record their hop-distance to other beacon nodes in the network. Secondly, beacon nodes estimate the average length for one hop (hop correction) and then broadcast this information to their neighbors. When a sensor node receives the first correction, it broadcast it to its neighbors, after that

the node does not wait for subsequent correction and can start the next step of the algorithm. Finally sensor nodes estimate their position according to the number of hops recorded for at least three known beacon nodes and to the hop correction, using trilateration or any other proper method [3].

#### **Amorphous Algorithm**

This technique is similar to the DV-hop method, but the amorphous algorithm assumes that nodes use the average length for one hop as the same communication path [11], therefore the accuracy of the estimated position of the sensor nodes is lower and the error range is larger. Amorphous method assumes that the average network connectivity is known in advance and additionally needs high density of beacon nodes; in consequence the expansion capability of the sensor network is bad.

#### **Approximate Point-in-triangulation Test (APIT)**

APIT [5] divides the neighbourhood area of a sensor node into many overlapped triangles according with the number of messages of different beacon nodes that is able to receive, and these beacon nodes become all the vertexes of the triangles. The sensor node is able to narrow down the area in which it may reside by checking whether it falls within the area of each triangle. Finally, utilizing the position information product of the combination of all audible beacon nodes, the size of the intersection area of triangles can be reduced, and the gravity of this intersection area is taken as the approximate location of the sensor node. APIT have a good performance in randomly deployed wireless sensor network. The accuracy of this method is high, but it has high demand of network connectivity.

#### **Centroid Algorithm**

In centroid algorithm the nodes receives signals of beacon messages in its communication area which contain location information, then estimates its coordinate as the centroid of these beacon nodes. The centroid method do not requires additional devices; therefore sensor nodes can have very simple hardware architecture. However, this algorithm is based in ideal propagation of radio signals, so it has low accuracy compared with other techniques [12].

### **3. Mobile Agents in Wireless Sensor Networks**

Most recently, a mobile agent approach is considered in several studies [13, 14, 15]; they propose the use of mobile beacons to accomplish the localization process of the sensor nodes. The use of mobile agents instead of fixed anchor nodes in WSNs has several advantages; the mobile nodes can help save energy in static sensor nodes during the localization process, extending their lifetime, additionally mobile agents are capable to perform several tasks related with the deploying, monitoring, maintenance and assurance of proper operation in order to achieve the mission of the network.

Another important benefit of applying a mobile agent approach in WSNs is that they can potentially reduce bandwidth consumption by moving the data processing elements to the location of the sensed data, whose transmissions in the raw otherwise would incur most of the energy expenditures of the nodes. This is highly appealing when large amounts of data have been collected and must be disseminated to the sink. In addition, mobile agent systems introduce a higher degree of WSN re-tasking flexibility, compared to other approaches, and facilitate collaborative information processing. Several other WSN issues, such as routing and data fusion can be effectively tackled by mobile agent systems.

The extra energy needed by mobile agents is not a major concern, because it is assumed that they can periodically recharge themselves, some works consider self recharging micro mobile robots equipped with solar panels, or using other sources like wind power and vibration energy collectors [16]. Moreover, mobile agents can be embedded in manned or unmanned mobile platforms, including the possible use of unmanned aerial vehicles (UAV) or mobile robots.

### **4. Nodes Localization Using an Unmanned Aerial Vehicle**

Some previous works are based in a mobile agent approach. In [13], authors proposed a mobile beacon node equipped with several directional antennas, digital compass, self positioning device and a transmitter capable of deliver several levels of power, its localization algorithm is based on restricted area determined by the beamwidth of the directional antennas and the distances ranges according with the difference of several transmitted powers emitted by the mobile beacon node. This approach rely on the use of several directional antennas therefore it needs a complex antenna control system, and due to the irregular radiation pattern of the directional antennas, it has to deal with the problem of overlapped sectors. Additionally this method is based on a sophisticated transmitter capable of deliver several levels of power.

In reference [14] Hong et al. consider the use of several mobile nodes equipped with GPS while RSSI devices are fitted to all sensor nodes, the localization method is based on trilateration when sensor nodes receive signals from at least 3 mobile beacons. As a consequence, this method requires the installation of additional hardware in the sensor nodes; besides it needs several mobile beacons.

The purpose of this paper is to propose an algorithm of range-free localization for WSNs using an unmanned aerial vehicle equipped with a rotary directional antenna. The localization method described in present work uses a unique unmanned aerial vehicle equipped with only one directional antenna, digital compass, self positioning device and a transmitter which send signals at merely one power level. The proposed algorithm, denominated azimuthally defined area localization algorithm (ADAL), is executed in each sensor node using just the information received from the UAV; therefore it is a distributed and energy efficient algorithm and contributes to extend the lifetime of the sensor network. Additionally the proposed algorithm has the advantage of being simple and economical. The simulation results show that the proposed algorithm is a practical, effective and accurate method for sensor nodes location in a WSN.

## 5. Network Assumptions

In the locating mechanism described by this paper, the following assumptions about the WSN are considered:

- There are a great number of randomly distributed sensor nodes, which are basically composed of an omni-directional antenna, low power transceiver, low capacity processor, battery and the respective sensor.
- There is at least one UAV, which is equipped with a rotary directional antenna, digital compass, self-positioning device and transmitter.
- The unmanned aerial vehicle is capable of flight over the whole network and broadcast the beacon messages to the sensor nodes during the localization process. Optimal trajectory of the UAV is not analyzed in this document.

## Antenna Considerations

Two types of antennas have been considered for this paper, the sensor nodes will use omnidirectional antennas, working only in reception mode during the localization process. On the other hand, the unmanned aerial vehicle will use a rotary directional antenna which rotates counterclockwise covering 360 degrees with an angular velocity  $w$ . To achieve the goal of this paper, the model of the directional antenna used in previous works is assumed [17, 18]; sidelobes and backlobes will be supposed to be too small compared with the mainlobe and can be neglected; these minor lobes will be consider in future work. The proposed algorithm assumes the directional antenna gain is within a specific angle  $\theta$ , where  $\theta$  is the beamwidth of the antenna. The gain outside the beamwidth is assumed to be zero. At any time, the antenna beam can only be pointed to a certain direction.

The maximum range of the directional antenna can be calculated using the Friis Equation [19], which establish the relation between transmit gain  $G_t$ , receive gain  $G_r$ , maximum transmit power  $P_{max}$  and the minimum required power at the receiving antenna to decode the signal beacon correctly  $P_{threshold}$ :

$$P_{threshold} = \frac{P_{max} G_t G_r}{K r_{max}^{\beta}} \quad (1)$$

Where the term  $K$  is a constant that depends of atmospheric absorption, ohmic losses and other factors,  $\beta$  is the path-loss index ( $2 \leq \beta \leq 4$ ), and  $r_{max}$  is the maximum distance between the unmanned aerial vehicle and the sensor node within which the sensor node can decode the beacon signal correctly. Reorganizing the above formula the maximum range of the directional antenna is:

$$r_{max} = \left( \frac{P_{max} G_t G_r}{K P_{threshold}} \right)^{\frac{1}{\beta}} \quad (2)$$

For the purpose of this work, the azimuth  $\alpha$  of the directional antenna is defined as the counterclockwise angle (measured in degrees) from its local positive x-axis to its boresight direction projection onto the local Cartesian coordinate xy-plane, as illustrated in Figure 1. Local coordinates correspond to the location of the UAV, only local abscissas and ordinates will be considered for the calculation of the sensor nodes position (without determining its altitude), as shown in Figure 2. The unmanned aerial vehicle can obtain the azimuth of the directional antenna in real time by means of the digital compass, which is installed to pointing to the local positive x-axis on the Cartesian coordinate plane.

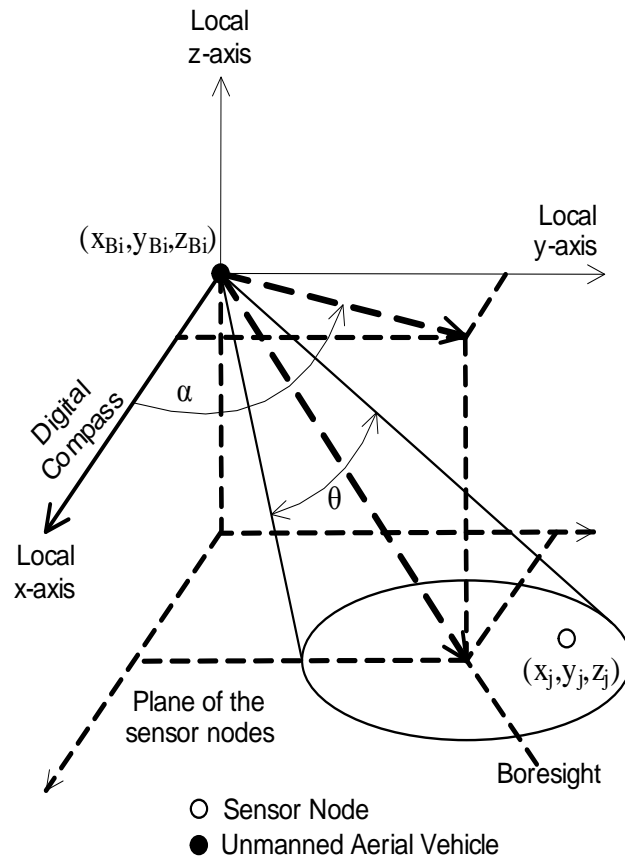


Figure 1. Azimuth of the directional antenna

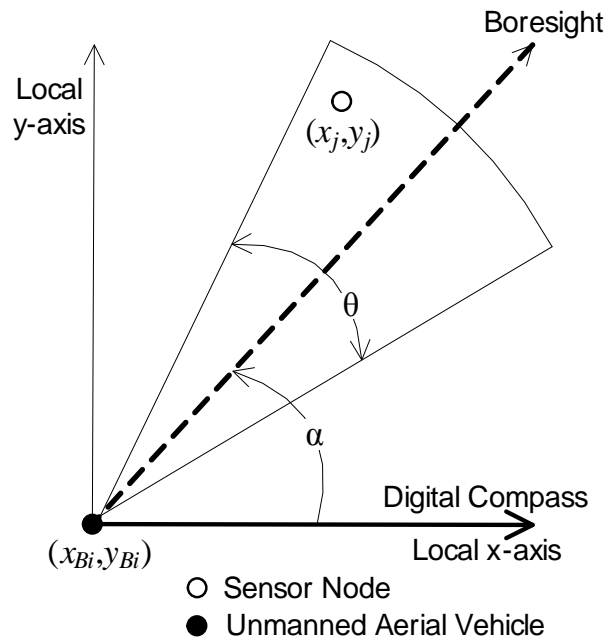


Figure 2. Coordinates of UAV and sensors nodes

## 6. Algorithm Description

In this section a detailed description of the proposed algorithm is given. As the unmanned aerial vehicle moves across the deployment area, like in Figure 3, the rotary directional antenna sends a virtual beacon message in a determined azimuth every  $t$  seconds. The virtual beacon message contains the following elements (see Figure 4).

- Identification number of the virtual beacon message.
- Real time coordinates of the UAV ( $x_{Bi}, y_{Bi}$ ).
- Azimuth of the directional antenna of the UAV ( $\alpha$ ).

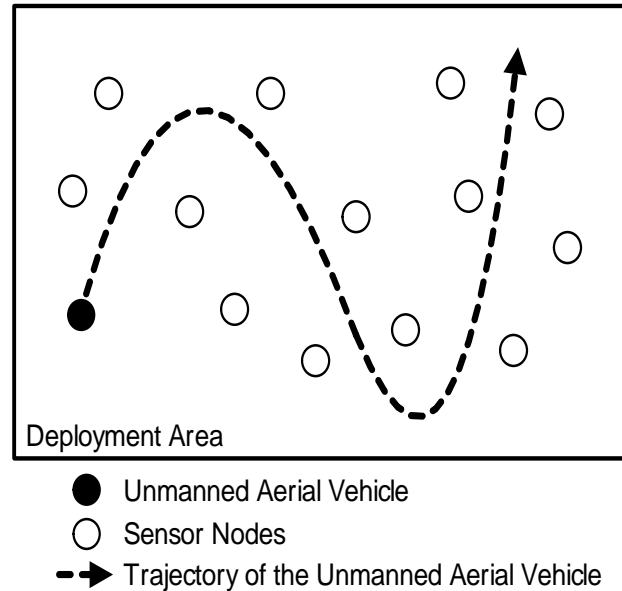


Figure 3. Trajectory of the unmanned aerial vehicle

Identification Number	Coordinates ( $x_{Bi}, y_{Bi}$ )	Antenna Azimuth ( $\alpha$ )
-----------------------	----------------------------------	------------------------------

Figure 4. Basic structure of the virtual beacon node data packet

When a sensor node is in the range of the directional antenna of the unmanned aerial vehicle, it receives a quantity of beacon messages that depends of the angular velocity  $w$  of the directional antenna, the time  $t$  between each transmission and the velocity  $v$  of the UAV. Each of these messages is called virtual beacon message, and are seen by sensor nodes as a several real fixed beacon nodes. The sensor nodes integrate all the received information to estimate its coordinates inside a possible localization region, as show in Figure 5.

The proposed method is iterative, and it compensates the irregular radiation pattern of the rotary directional antenna by processing several data packets, the accuracy of the position estimation of the sensor node is proportional with the quantity of virtual beacon messages that it receives. The localization process can be divided into three phases:

### 6.1 Initialization Phase

In this phase are established important parameters such as the beamwidth of the directional antenna ( $\theta$ ), transmit and receive gains ( $G_t$  and  $G_r$  respectively), maximum transmit power of the directional antenna ( $P_{max}$ ) and minimum required power at the sensor nodes antennas ( $P_{threshold}$ ).

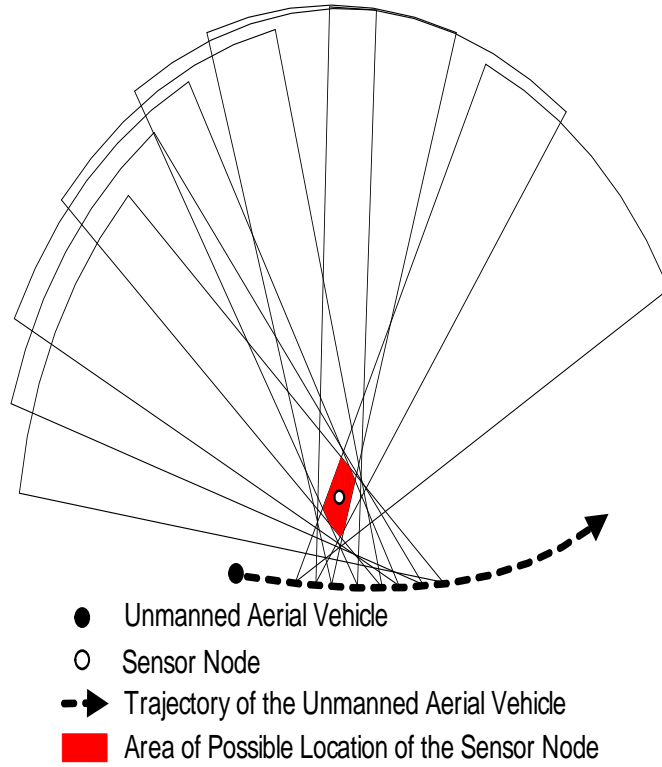


Figure 5. Estimation of coordinates of a sensor node

## 6.2 Localization Phase

In the second phase, the proposed azimuthally defined area localization (ADAL) algorithm is used to accomplish the preliminary position estimation. In this stage the sensor nodes begin to receive the virtual beacon messages, each virtual beacon information package is composed of virtual beacon node identification, virtual beacon node localization and azimuth of the pointing direction of the directional antenna. If a sensor node receives a virtual beacon message, it defines a polygonal approximation of a circular sector defined by the real time localization coordinates of the unmanned aerial vehicle ( $x_{Bi}, y_{Bi}$ ) and the maximum range  $r_{max}$ , beamwidth  $\theta$  and azimuth  $\alpha$  of the directional antenna (see Figures 1, 2).

When a sensor node receives the first virtual beacon message, it establish a preliminary area and the estimation of its position ( $x_{ej}, y_{ej}$ ) is the centroid of this area. After that, each time a virtual beacon message is received, the sensor node determines the intersection area of the circular sector and the preliminary area. To accomplish this task, it conforms a set of points including the vertexes of the polygons of the preliminary area and the approximation of the circular sector, and the intersection points of the boundaries of this two polygons, then the convex hull of this set of points is determined in order to define the new preliminary area, after that the resulting surface is meshed triangularly using the Delaunay triangulation algorithm.

The convex hull corresponds to the boundary of the minimal convex set containing a given non-empty finite set of points in the plane, unless the points are collinear, the convex hull is a simple closed polygonal chain [20], as shown in Figure 6. The convex hull of a set of points  $P$  in  $n$  dimensions is the intersection of all convex sets containing  $P$ . For  $k$  points  $p_1, \dots, p_k$ , the convex hull  $H(P)$  of set  $P$  is then given by the expression:

$$H(P) = \left\{ \sum_{i=1}^k \tau_i p_i \mid p_i \in P, \tau_i \in \mathbb{R}, \tau_i \geq 0, \sum_{i=1}^k \tau_i = 1, k = 1, 2, \dots \right\} \quad (3)$$



A Delaunay triangulation for a set  $P$  of points in the plane is a triangulation  $DT(P)$  such that no point in  $P$  is inside the circumcircle of any triangle in  $DT(P)$  [21], as illustrated in Figure 7. Delaunay triangulations maximize the minimum angle of all the angles of the triangles in the mesh. To detect if a point  $D$  lies in the circumcircle of  $A, B, C$  (lying counterclockwise) the following determinant is evaluated, it is positive if and only if  $D$  lies in the circumcircle:

$$\begin{vmatrix} A_x & A_y & A_x^2 + A_y^2 & 1 \\ B_x & B_y & B_x^2 + B_y^2 & 1 \\ C_x & C_y & C_x^2 + C_y^2 & 1 \\ D_x & D_y & D_x^2 + D_y^2 & 1 \end{vmatrix} \quad (4)$$

$$= \begin{vmatrix} A_x - D_x & A_y - D_y & (A_x - D_x)^2 - (A_y - D_y)^2 \\ B_x - D_x & B_y - D_y & (B_x - D_x)^2 - (B_y - D_y)^2 \\ C_x - D_x & C_y - D_y & (C_x - D_x)^2 - (C_y - D_y)^2 \end{vmatrix} > 0$$

Once the intersection area is triangularly meshed, all patches  $T_i$  of the mesh are defined by its 3 vertexes  $(x_{1i}, y_{1i}), (x_{2i}, y_{2i}), (x_{3i}, y_{3i})$ ; then the area and centroid of each patch of the mesh is calculated using the following formulas:

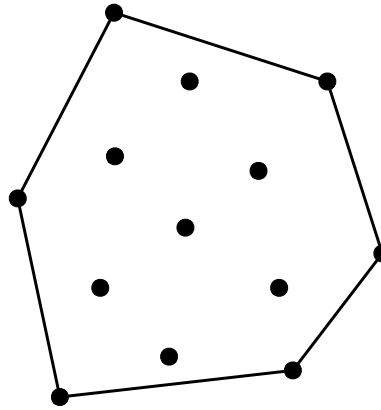


Figure 6. Convex hull of a set of points

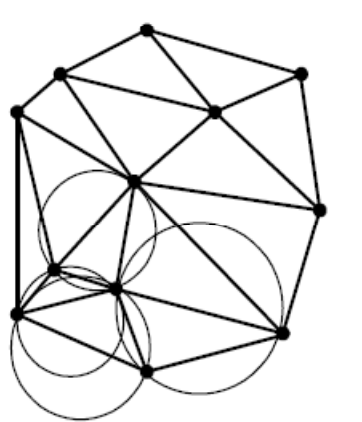


Figure 7. Example of a Delaunay triangulation



$$x_{ci} = \frac{x_{1i} + x_{2i} + x_{3i}}{3} \quad (5)$$

$$y_{ci} = \frac{y_{1i} + y_{2i} + y_{3i}}{3}$$

$$A_i = \frac{1}{2} \left| \det \begin{bmatrix} x_{1i} & y_{1i} & 1 \\ x_{2i} & y_{2i} & 1 \\ x_{3i} & y_{3i} & 1 \end{bmatrix} \right| \quad (6)$$

Where  $(x_{ci}, y_{ci})$  and  $A_i$  are the coordinates of the centroid and the area of each patch  $T_i$  of the mesh respectively. Finally, the new estimation of the coordinates  $(x_{ej}, y_{ej})$  of the sensor node corresponds with the coordinates of the centroid of the whole intersection area, and is determined by integration of all the centroids and areas, using the following formulas:

$$x_{ej} = \frac{\sum_{i=1}^n x_{ci} A_i}{\sum_{i=1}^n A_i} \quad (7)$$

$$y_{ej} = \frac{\sum_{i=1}^n y_{ci} A_i}{\sum_{i=1}^n A_i}$$

Figure 8 shows the principle of the algorithm representing the sensor node receiving three virtual beacon nodes, it can be seen that the accuracy of the estimation of its position is increased each time a virtual beacon node is processed.

Summarizing, every time that sensor node receives a new virtual beacon message, it determines the intersection of the previously calculated area with the new circular sector and calculates the new centroid of the resultant area as the estimation of its approximate location. The following figure shows the detailed algorithm for the second phase:

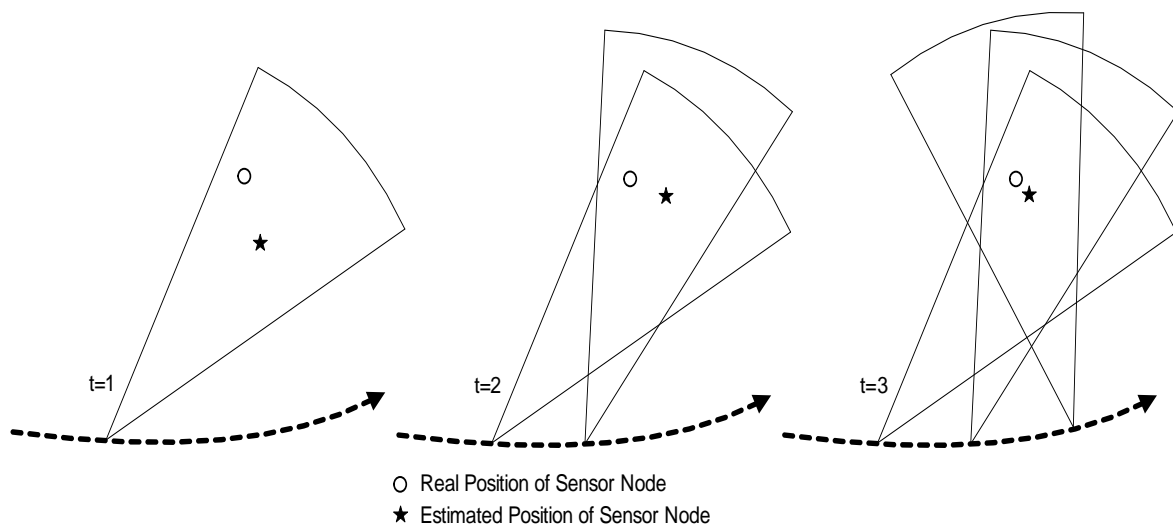


Figure 8. Location estimation of a sensor node

```

ADAL algorithm
if (sensor node receive a virtual beacon message)
{
  compute NB = number of received beacon messages;
  if NB = 1
  {
    determine a circular sector region using  $(x_{Bi}, y_{Bi})$ ,  $r_{max}$ ,  $\theta$  and  $\alpha$ ;
    determine a polygonal approximation of the area of this circular sector;
    define this polygon =  $A_p$ ;
    calculate the centroid of  $A_p = (x_{ej}, y_{ej})$ ;
    coordinates of sensor node =  $(x_{ej}, y_{ej})$ ;
  }
  end
  if (NB  $\geq$  2)
  {
    determine a circular sector region using  $(x_{Bi}, y_{Bi})$ ,  $r_{max}$ ,  $\theta$  and  $\alpha$ ;
    determine a polygonal approximation of the area of this circular sector;
    define this polygon =  $A_N$ ;
    if (it exist intersection points of the boundary lines of  $A_p$  and  $A_N$ )
    {
      these points define the set S;
    }
    Else
    {
      coordinates of sensor node =  $(x_{ej}, y_{ej})$ ;
      exit;
    }
    end
    select the vertexes of  $A_p$  inside the area  $A_N$  and add it to S;
    select the vertexes of  $A_N$  inside the area  $A_p$  and add it to S;
    define a polygon by determine the convex hull of S;
    define this polygon =  $A_p$ ;
    mesh area  $A_p$  triangularly using the delaunay method;
    calculate the areas of all triangular patches of polygon  $A_p$  using (6);
    define this areas =  $A_1, A_2, A_3, \dots, A_i$ ;
    calculate the coordinates of the centroids of all these triangular pachts using (5) =  $(x_{c1}, y_{c1}), (x_{c2}, y_{c2}), \dots, (x_{ci}, y_{ci})$ ;
    calculate the centroid of  $A_p$  by integration of all  $(x_{ci}, y_{ci})$  using (7) =  $(x_{ej}, y_{ej})$ ;
    coordinates of sensor node =  $(x_{ej}, y_{ej})$ ;
  }
else
coordinates of sensor node = (0,0);
}
end

```

Figure 9. Detailed ADAL algorithm

### 6.3 Refinement phase

In this stage a refinement of the preliminary estimation of the position made in the previous phase is performed, the unmanned aerial vehicle continues to move around the network, and while execute several other tasks in relation with its operational function, take advantage of this fact and send more virtual beacon messages in order to reach a progressively greater precision in the estimation of each sensor node position.

## 7. Performance of the Algorithm

In this section the results of several simulations to test the algorithm are shown, the software used for the simulations was Matlab.

The criterion used for the estimation error ( $E$ ) was the ratio of the distance between real  $(x_j, y_j)$  and estimated  $(x_{ej}, y_{ej})$  coordinates to the number of sensor nodes ( $n$ ). The estimation error is useful to show the degree of the estimation accuracy that the algorithm can achieve. Smaller estimation errors indicate better estimation accuracies.

$$E = \frac{\sum_{j=1}^n \sqrt{(x_{ej} - x_j)^2 + (y_{ej} - y_j)^2}}{n} \quad (8)$$

### 7.1 Simulation Conditions and Parameters

The simulations were done using a random deployment of 500 sensor nodes in a square area of 100m<sup>2</sup>, as shown in Figure 10. The sensor nodes were considered to reside in a two-dimensional plane, and the UAV moves over the network in another parallel two-dimensional plane. The parameters used are.

- *Beacon density*: the number of beacon nodes or virtual beacon nodes in the deployment area. For the unmanned aerial vehicle this parameter is determined by its trajectory and velocity, and the transmission frequency of the beacon messages.
- *Radio transmission range*: the maximum distance of communication between the unmanned aerial vehicle and sensor nodes, for the simulations is fixed in 20m.
- *Beamwidth*: the angular separation of the region where it is assumed to be distributed the gain of the directional antenna.

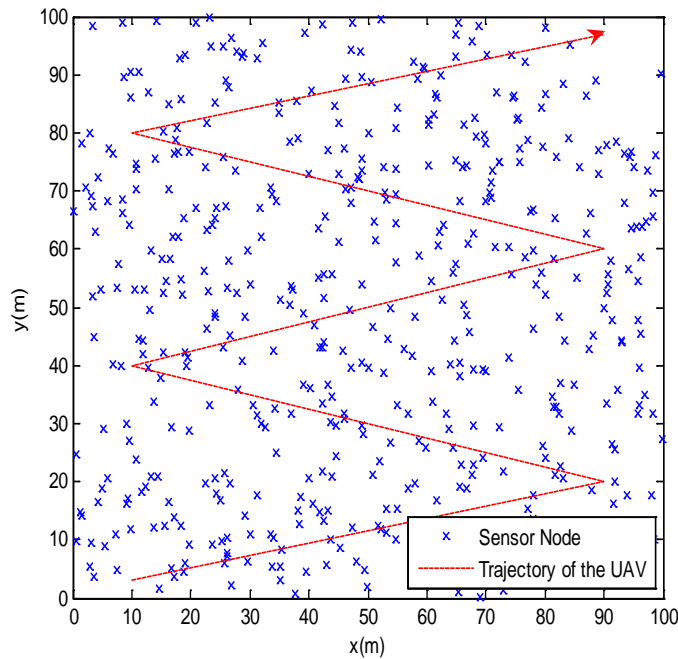


Figure 10. Deployment of sensor nodes and trajectory of the UAV

### 7.2 Simulation Results

Figure 11 shows the performance of the ADAL algorithm considering different beamwidths of the directional antenna, it can be seen that if the number of virtual beacon nodes is incremented the estimation error is lower, this fact is because as more virtual beacons are processed in the sensor nodes the possible area of its location is decreased and the estimation of its position is better.

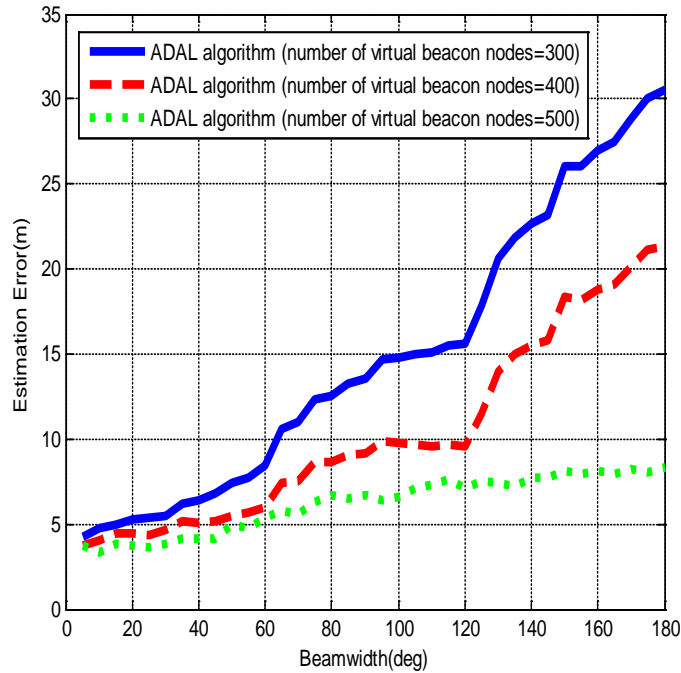


Figure 11. Performance of ADAL algorithm according with the beamwidth of directional antenna

In Figure 12 it can be seen the comparison of the proposed algorithm with the DV-Hop algorithm, which is representative of the range-free methods. Clearly the performance of the ADAL algorithm is better in the cases using directional antennas of 45 and 60 degrees. It can be observed that the estimation error is decreased as the beamwidth of the directional antenna is smaller; when the beamwidth is 45 degrees the estimation error is lower than 6m.

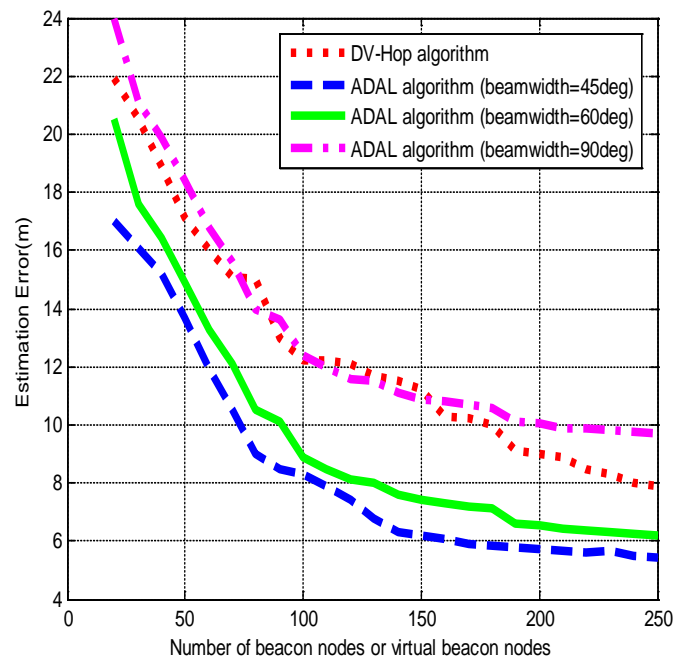


Figure 12. Comparison of ADAL and DV-Hop algorithms

Figure 13 shows the comparison of the performance of a range-based algorithm, the maximum likelihood estimation (MLE), and the ADAL algorithm. It is evident that range-based methods have a better performance, but the proposed algorithm have the capacity of get closer to acceptable estimation errors by decreasing the beamwidth of the directional antenna, or if this is not possible, by increasing the number of virtual beacon nodes.

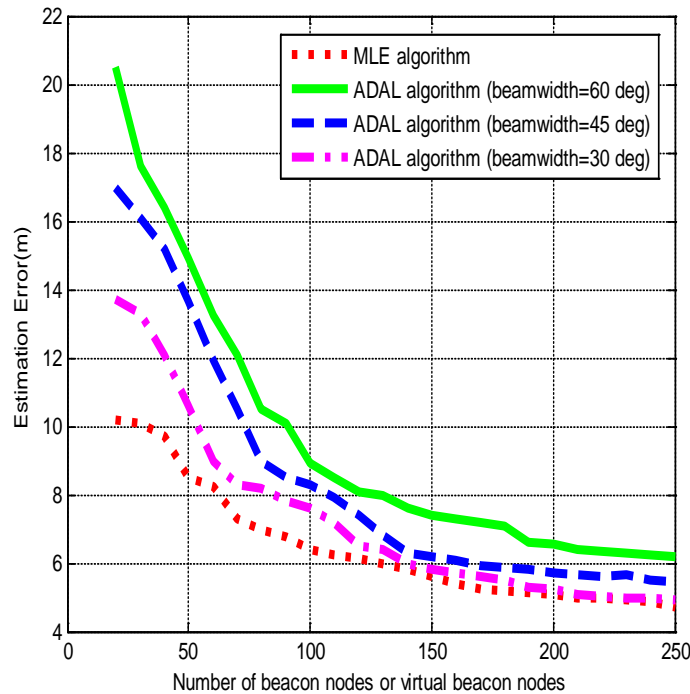


Figure 13. Comparison of ADAL and MLE algorithms

## 8. Conclusions and Future Work

This paper proposes a range-free localization algorithm for WSN using an unmanned aerial vehicle with a rotary directional antenna. In the proposed algorithm the sensor nodes only need to receive information from the unmanned aerial vehicle to determine its position, therefore the sensor nodes don't require additional equipment neither spend energy in data transmission, as a consequence the lifetime of the network is longer and the design of sensor nodes can be maintained as simple as possible. The simulation results show that the ADAL algorithm is a practical and effective method for sensors node location in a WSN, with accuracy suitable for most of real applications.

Future work includes the use of a more realistic model of the directional antenna considering the minor lobes, and a routing algorithm using the unmanned aerial vehicle configured to accomplish large distance data communications of the WSN by means of a satellite link.

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