

Analysis of Localization for Drone-fleet

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Abstract—Generally in mobile devices, localization is a critical issue to provide various services. A common way to find location is to use GPS. However, GPS has several limitations such as its reliability. Especially in none line of sight (NLOS) situations such as indoor environment, GPS is unable to find location. This could be a serious issue for drone fleet because we may lose control of drones. In this paper, we present a comprehensive survey on effective solutions for complementing GPS for drone fleet. In particular, we introduce several localization techniques that are independent of GPS. Since each technique has its own advantage as well as disadvantage. Hence, we categorize these localization techniques in order to find which technique is suitable for drone fleet.

Keywords— Localization, Aerial Network, Drone, Location estimation, Mobile Network, Wireless sensor networks.

I. INTRODUCTION

A drone, or an unmanned aerial vehicle (UAV), is an aircraft which is remotely piloted. Drones are originally developed for military purpose. However, nowadays consumer market is also quickly growing for variety fields such as medical, meteorology, science, art, and so on. Since a drone can overcome its physical obstacles by its movement, it is a promising technology for future society. Furthermore, drone technology is attracting quite significant research interest.

In this paper, we present a comprehensive survey on the state-of-the-art research concerning localization techniques which can be applied to drone fleets.

Drone is a mobile and aerial object, so it can easily disappear from sight. Naturally, localization has become a vital research area nowadays for drones. Conventional localization technique is related to mobile wireless sensor networks (WSNs). However, it is partly unsuitable with localization for network drone fleet. First, drone fleet could vertical move to aerial area. Sensor, car and phone mostly make horizontal move, so localization concept and approach should be changed. Second, drones change environment frequently. Usual aircraft departs from land to execute its mission and come to the ground after mission completed. However, drones easily come and go between land and aerial area. Consequently, Localization techniques for drone fleet need to consider environmental change. Third, location estimation error is critical to drone. If location estimation error occur to WSNs, it only affects mission achievement. In case of drones, location error may result in collision, which can be a harm to drone hardware, or even more seriously to humans.

II. LOCALIZATION TECHNIQUES

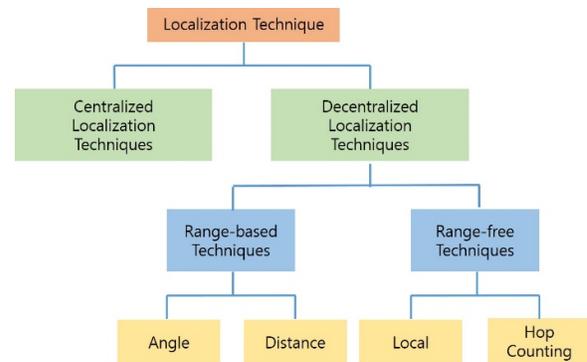


Figure 1. Localization Techniques.

According to [1], localization techniques can mainly be divided into two categories by node organizational structure: centralized and decentralized techniques. Decentralized localization is further divided into two categories based on how to calculate location between each node, i.e., range-based techniques and range-free techniques as shown in Figure 1 [2].

Many localization techniques used in the field are pertained to range-based techniques. They can be divided by their characteristics such as angle and distance [3]. Range-free methods can also be divided by local hop counting [4]. Localization techniques can also be divided into different ways such as anchor/beacon based or anchor/beacon free, GPS based or GPS free, fine grained or coarse grained, stationary or mobile sensor nodes, etc. [5].

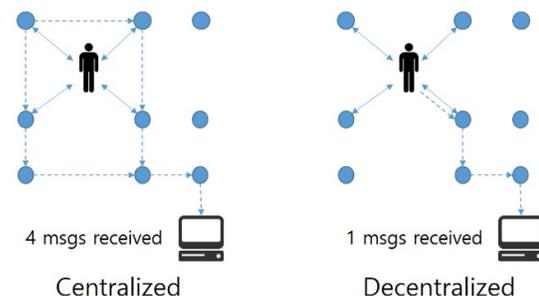


Figure 2. Node organization structures.

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A. Centralized Localization Techniques

Centralized localization techniques transmit data to a central node and then central node computes location information about every node. In [6], the authors proposed a centralized technique, which is a method for estimating unknown node positions by using convex optimization. It is based on connectivity-induced constraints. MDS-MAP [7] also presents an algorithm that uses connectivity information by using a multidimensional scaling (MDS). MDS-MAP uses much less information, and recovers more accurate maps of node location.

These centralized localization techniques have an advantage that nodes do not need expensive and sophisticated sensors such as GPS. Another advantage is that nodes do not require computation cost to calculate location because the central node is responsible for computation. However, centralized localization techniques also have some disadvantages. Every node sends information to the central node, which requires large communication cost, large bandwidth, and larger delay. Especially, large communication cost is a serious problem for drone-fleet because drones are usually very sensitive with battery consumption. Frequent communication to the central node needs higher energy consumption. Consequently, centralized localization techniques may be unsuitable for drone-fleet.

B. Decentralized Localization Techniques

Decentralized localization techniques transmit data to nearby nodes. They do not rely on centralized computation, so they are able to determine their locations with only limited communication. This approach is more suitable for drone-fleet than centralized localization techniques. These techniques can be classified as range-based and range free techniques.

1) *Range-based Localization Techniques*: These techniques estimate the distance or angle between nodes, and find their location usually by trilateration. These range-based techniques include most common localization techniques such as GPS, RSSI, TOA, TDOA, AOA, and so on. Typically, more accurate range-based localization techniques are more complex [4]. How to mitigate this tradeoff is a critical issue in the field.

a) *Global Positioning System (GPS)*: GPS is the most famous and general localization technique in the world. It has been developed as military purpose, but nowadays It is open to public. GPS uses the TOA-based distance estimate technique and the trilateration technique between at least three satellites. In addition, the fourth satellite assists for time synchronization. In GPS, time sync is critical for accuracy, and hence it uses an atomic clock at each satellite. By using GPS, a mobile node can easily synchronize time without its own atomic clock. GPS could be the simplest technique for localization. However, It has some limitations to be applied to drone fleet. First, GPS receivers are expensive for large-scale drone fleet. Second, GPS is typically do not work in none line of sight (NLOS) environment especially such as indoor situation [8]. Third, its energy consumption is larger than other techniques. Fourth, GPS receivers communicate with satellites, and hence the communication distance is much longer than other techniques, which is a vulnerable point for jamming attacks.

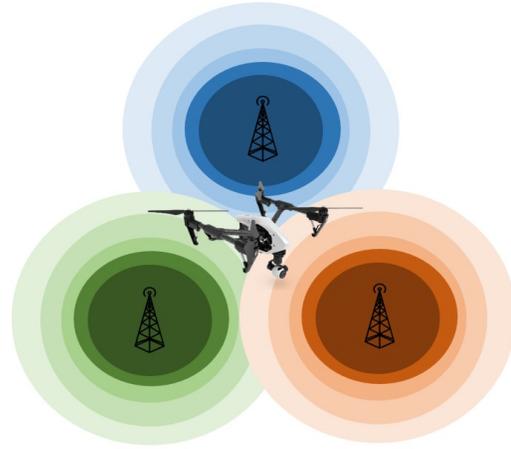


Figure 3. RSSI localization overview.

b) *Received Signal Strength Indication (RSSI)*: RSSI is the technique, which is measuring the power of signal strength at the receiver [9]. Propagation loss is calculated to improve its accuracy, and measured signal strength can be converted to the distance between the transmitter and the receiver. In free space, as the distance between transmitter and receiver changes, the signal strength also changes. This can be measured by using the following Friis equation [10]:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2}, \quad (1)$$

Where P_t = transmit power, G_t = transmitter antenna gain, G_r = receiver antenna gain, and λ = wavelength of the transmitter signal in meters. Nodes can calculate the distance between the transmitter and the receiver. Trilateration technique applies to find location by distance. This technique is very simple to apply because most receiver can estimate RSSI. Hence, it does not require any further hardware. Also, its computation to estimate distance and find location is quite cheap. However, accuracy of this technique varies according to environment while drone fleet is very sensitive with location accuracy. If location is inaccurate, drones can make collision. Hence, to apply the RSSI method needs more through research.

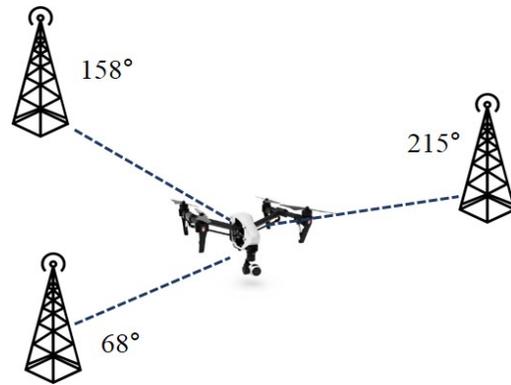


Figure 4. AOA localization overview.

c) *Angle of Arrival (AOA)*: AOA is a method that finds location by the angle estimate between the direction of an incident wave and a certain reference direction [11]. It uses multi-array antennas to estimate the direction of the signal. This technique requires at least two nodes in the ideal case. If nodes are on a straight line, It cannot estimate the location of the target node. In this case, additional node is required to securely find the location. AOA technique is related to the basic beamforming technique. Both techniques require antenna rotation by mechanically or electronically [12]. An issue is that this concept requires additional hardware, which increases hardware cost and weight [13]. Hence, it is hard to be applied to the drone fleet. Another problem is that this technique is severely affected by NLOS situations. Its accuracy is limited by the directivity of the antenna, by shadowing and by multipath reflections. In summary, AOA is not an adequate technique for drone fleet, but still beamforming is a promising technique for 5th generation wireless systems (5G).

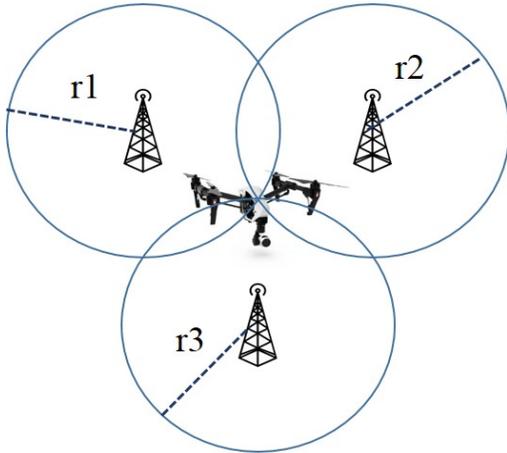


Figure 5. TOA localization overview.

d) *Time of Arrival (TOA)*: TOA measures the propagation time between nodes by calculating the time of the transmitter and the time of the receiver. This technique can be divided into one-way ranging (OWR) and two-way ranging (TWR). OWR estimates the time difference between transmit time and received time. TWR estimates the signal propagation round-trip time (RTT) without time synchronization. Naturally, time synchronization is essential to use this technique. 3 ns error of TOA can make approximately one-meter error in distance estimation because the high speed of wireless signal propagation [15]. High-resolution precise clocks such as atomic clocks of GPS satellites are impractical to be applied to mobile nodes. Real-time synchronization can be a solution. There are two ways to sync the timer in mobile nodes. The first way is to use GPS. However, in this paper, we consider GPS-free techniques. Second way is using networks. It is also hard to apply because its time synchronization is not accurate. TOA distance can be measured by following equation:

$$r_i = C \times (t_o - t_i), \quad (2)$$

Where C = radio speed, t_o is the time when the receiver receives the signal, t_i is the time when transmitter transmits. Its disadvantage is that TOA technique is also affected by NLOS situation. In case of TWR, it is less sensitive to time synchronization than OWR. However, it requires more energy to transmit signal, and its computation cost is high.

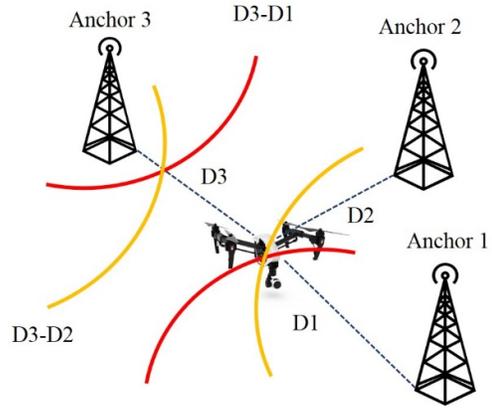


Figure 6. TDOA localization overview.

e) *Time Difference of Arrival (TDOA)*: TDOA is based on the measurement of the difference in the arrival times of the signal from the source at multiple nodes. This technique is normally implemented by taking a snapshot of the signal at a synchronized time period at multiple nodes [16]. A general approach to estimating TDOA is to calculate the cross correlation between signals arriving at two nodes. These two time difference information yields a hyperbolic curve equations [17]. The Hyperbola curve suggests two point where node may exist. We can find the location of nodes by using two hyperbolic curve equations. TDOA technique has several advantages. For example, it does not require specific hardware, and this solution is more cost effective than GPS. It also does not require time synchronization about nodes. Most of all, TDOA is less affected by radio reflection. It is more accurate than TOA in NLOS situation. Another technique of TDOA is to send different signals simultaneously. This technique is more simple, but it requires additional hardware to send two signals.

2) *Range-free Localization Techniques*: Range-free localization is mainly classified into two categories. The accuracy of location estimate is usually smaller than range-based localization techniques.

a) *Local technique*: These methods rely on a high density of nodes. centroid localization technique [18] proposes a range-free, proximity-based, coarse grained localization technique. This technique is suitable for small, energy efficient nodes without GPS. It is based on the spherical radio propagation assumption. This technique finds the location by calculating the center of the location of all nodes it can hear. In an approximate point in triangulation (APIT) localization technique [19], an area-based, range-free localization approach is proposed. This technique requires a heterogeneous network of sensing devices. APIT employs a novel area-based approach to estimate location.

it is based on isolating the environment into triangular regions between nodes as shown in Figure 7.

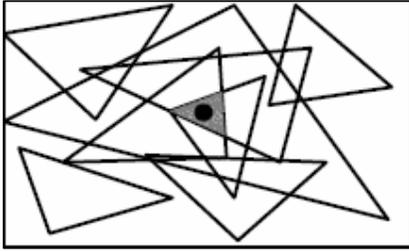


Figure 7. APIT localization overview.

b) *Hop Counting Techniques:* These methods rely on flooding. Distance vector-hop (DV-Hop) localization techniques [20] uses a similar mechanism with classical distance vector routing [21]. This technique estimates the distance between the unknown nodes and the reference nodes are expressed by the product of the average hop distance and the hop count [22].

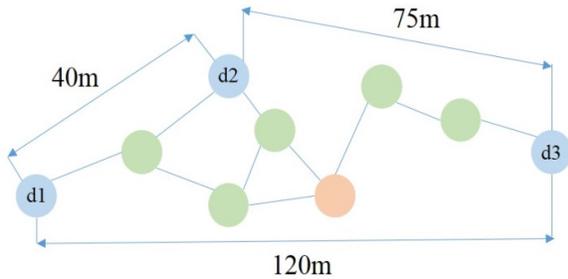


Figure 8. DV-Hop localization overview.

The amorphous localization technique [23] uses a similar approach with DV-Hop. The coordinates of nodes are flooded throughout the network so that each node can maintain a hop-count to that node. Nodes estimate their location based on the received node locations and the corresponding hop count. These techniques are less accurate than range-based techniques, but they do not be affected by NLOS situation.

III. RECENT RESEARCH

As already mentioned, TDOA is suitable for the drone-fleet instead of GPS. However, when a drone is unable to use GPS, TDOA may not work properly as shown in figure 9 [24].

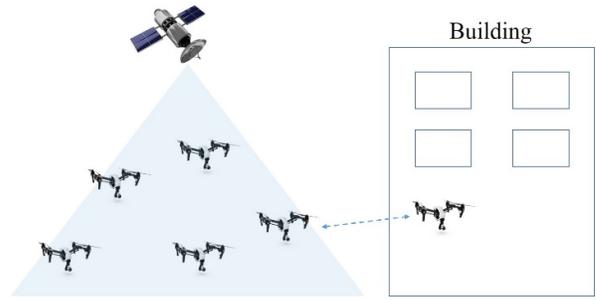


Figure 9. Drone-fleet localization over GPS range.

Hence, we look into range-free localization techniques, especially DV-Hop because it works well when nodes density is low that matches well with the drone fleet. There are several improved techniques based on DV-Hop.

A. DV-Hop based algorithm

The original DV-Hop algorithm consists of three steps. First, the anchor nodes A_i broadcast a message, which contains the position of A_i . Second, when anchor nodes A_i receive the message, they calculate the average distance per hop (DPH). Third, when the unknown nodes U_i obtain the distance information from anchor nodes A_i , trilateral measuring method or maximum likelihood measuring method is used to calculate the location of unknown node U_i . Differential DV-Hop (DDV-Hop) [25] changes some steps from original DV-Hop algorithm. In step 2, DV-Hop broadcast only DPH information, but DDV-hop includes differential error of DPH. In step 3, DDV-hop differently calculates for measuring distance. Checkout DV-Hop (CDV-Hop) [26] measures the mobile node position by using the nearest anchor node. We need to improve these techniques to guarantee localization accuracy.

B. DV-Hop with random mobility models

Original DV-Hop technology and some improved techniques do not consider mobile wireless sensor networks (MWSNs) such as the drone-fleet. In [27], the authors target to quantify the impact of mobility on localization, where several mobility models are compared.

1) *Random waypoint model (RWP):* RWP [28] is a random model for the movement of mobile users. It often used in ad hoc network simulations because it is easy to implement for process simulation. In this mobility model, nodes wait for some period, and they move to random direction with a random speed. When they arrive at destination, they repeat the same process.

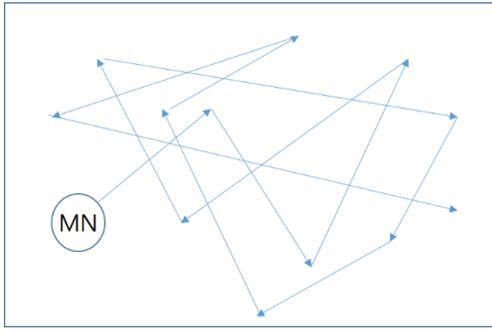


Figure 10. Random Waypoint Mobility Model.

2) *Random direction model (RD)*: RD [29] is similar to RWP. In RD, mobile nodes move to random direction in 0 to 359 degrees, but when it reaches its boundary, It changes its available degree 0 to 180 degrees.

3) *Reference point group mobility (RPGM)*: RPGM [30] is applied to group mobility. It considers many cases, where a group of members move together.

Mobility models affect performance of DV-Hop. So a proper mobility model is important to DV-Hop algorithm. Mobility models should be more realistic for the drone-fleet because current mobility models aim at conventional mobile nodes such as car, human, and so on.

IV. SUMMARY OF EXISTING TECHNIQUES

A. Strength and Weakness

1) *MDS-MAP*: No need for additional hardware. Cost is low while accuracy is low.

2) *GPS*: Simple to use. Some cases, It does not work under indoor situation. Hardware cost and energy consumption are high.

3) *RSSI*: It is a low cost technique because most receivers can basically estimate RSSI. Its accuracy is not reliable because of its dependency on environment.

4) *AOA*: Requires additional hardware. Hardware size and cost increases. Its accuracy also depends on NLOS situation.

5) *TOA*: No need for additional hardware. OWR requires perfect time synchronization. TWR require additional computation cost. Affected by reflecting, multipath signal propagation.

6) *TDOA*: Requires less precise time synchronization. Its accuracy is quiet high. It is affected by reflecting, multipath signal propagation.

7) *Centroid*: Easy to implement. It requires placement of anchors in a square mesh.

8) *APIT*: It is not affected by environment. Energy consumption is low. Accuracy is not reliable.

9) *DV-Hop*: It is not affected by environment. Energy consumption is low. Accuracy is not reliable.

We now give a summarized comparison between existing localization techniques so far. The result is given in Table 1 [2, 9, 19, 31-33].

Table 1. Comparison of localization techniques.

Technique	Cost	Accuracy	Energy Consumption	Additional Hardware
MDS-MAP	High	Medium	High	x
GPS	High	High	High	o
RSSI	Low	Medium	Low	x
AOA	High	Low	Medium	o
TOA	High	Medium	High	x
TDOA	Low	High	Low	x
Centroid	Low	Medium	Low	x
APIT	Medium	Medium	Low	x
DV-Hop	Low	Medium	Low	x

V. CONCLUSION AND FUTURE WORK

We have analyzed general localization techniques. Each one has its own advantages and disadvantages. Hence, it is not easy to tell which technique is optimal for drone fleet. Still, it is obvious that GPS is a very powerful localization technique. A centralized technique such as MDS-MAP has little merit to use. RSSI-based techniques are quite simple, but they will introduce too much location error. AOA techniques are not very suitable for mobile nodes because additional hardware will increase cost as well as weight. TOA, TDOA, and range-free techniques are more promising. However, TOA, TDOA techniques can introduce considerable error without GPS. Hence, we are currently planning to carry out further research about range-free techniques for drone fleet. We will focus on how to improve the DV-Hop algorithm to increase its accuracy. We will also adopt an improved mobility model which takes into account drone-fleet velocity, direction, and height.

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