A clustering method for energy efficient management of heterogeneous nodes of a flying ad hoc network

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ABSTRACT

The current paper presents a clustering method for energy efficient management of heterogeneous nodes of a flying ad hoc network (FANET). The technological advances of the last decade gave rise to emerging technologies. Unmanned aerial vehicles (UAVs) are small aircraft that proved their usefulness for different tasks nowadays. They can collaborate to achieve missions especially in areas where traditional networks cannot work or cannot accede. A FANET is composed by a number of these aircraft. For alike networks, the resources are limited. Indeed, an efficient energy management is required to extend the life of the network. This work is a clustering method for heterogeneous nodes of a FANET, each node is equipped with one sensor, and four different sensors are used. Clustering is grouping nodes with the aim of efficiency improvement. The clustering is done before the beginning of the rescue mission and depends on the types of sensors the nodes are equipped with and. The master election depends on the available energy of each one of the nodes. The simulation is done with a discrete event simulator (DES) and the results are compared to the algorithm of glowworm swarm optimization (GSO) to demonstrate the effectiveness of the suggested technique.

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1. INTRODUCTION

The last decade was characterized by the rise of new technologies and the creation of new types of networks. For example, an ad hoc network is an infrastructure-less network that don't rely on already existing infrastructures for instance access points or routers. The origin of ad hoc networks can be traced to the beginning of the 1970s, when a research agency of the Defense Department of the United States named the defense advanced research projects agency (DARPA), sponsored a project of several wireless terminals that can communicate with each other on battlefields known as the packet radio network [1]. After that project, different types of ad hoc networks were created first for military uses and after, were applied to civilian uses; the most known types are the mobile ad hoc networks (MANETs), the vehicular ad hoc networks (VANETs), and the wireless sensor networks (WSNs) where the nods are respectively, mobile devices, vehicles, and wireless sensors [2]. Each type has its own specifications but they also share some features for instance the high number of nodes and the non-reliability of the infrastructure that generally characterize ad hoc networks.

These networks were used in many applications and were also extended to other areas of work like the 3D spaces (water, sky …). In all ad hoc networks, topology management is a main challenge to overcome [3].

This article is limited to flying ad hoc networks (FANETs), infrastructure-less networks where the nodes are unmanned aerial vehicles (UAVs). An UAV is an aircraft that is controlled remotely or independently always without on board human control [4]. Nowadays, everybody knows about the existence of these technologies and their use is significantly increasing all over the world. New UAVs applications were developed for many uses [5] and they were also combined with existing technologies to resolve certain challenges. The main characteristics of these type of ad hoc networks are the high mobility of flying UAVs, the recurrent changes in topology and the absence of a central authority to manage the security. FANETs can autonomously perform missions mainly monitoring, localizing, and delivering. They are used in different civilian and military applications like search and rescue missions, agriculture, as well as for telecommunication by integrating UAVs into cellular networks [6]. Because of their unique characteristics, such networks face some limitations (like security and routing) [7]. One important issue is the energy limitations because the UAV's energy sources came in many different forms and generally rely on on-board battery that have a determined lifetime or on other means of power providing [8]. Finding the most optimal ways to consume energy becomes then an important challenge to overcome in FANETs. Each node has an initial energy that is reduced during its flight, this energy depends on how each of the different components consumes energy and more important, the techniques used by the nodes to acquire energy [9].

In the majority of works, the batteries used by the flying nodes are the lithium polymer (LiPo) batteries that have a light weight and a high energy density [10]. Other types of batteries exit in the market, composed by other elements, each by its benefits. However, until now, researches are still searching the best and optimal ways of drone's energy providing. As an example, the solar cells, the fuel cells and the hybrid techniques that combine two or more energy source providing [10]. Regardless of the means of power providing, the topology management can be a solution to that issue. It is the management and the organization of mobile nodes in a network that aims at conserving energy and maintaining the network connectivity. It consists of recognizing the physical and the logical connections between the nodes. Different algorithms of topology management exist in the research literature and can be categorized into three main groups: topology discovery, sleep cycle management, and clustering. The first category, topology discovery is the process of discovering and mapping network nodes to maintain the network efficiency [11]. The second category, the sleep cycle management is to allow some nodes to sleep and conserve their energy [12]. And finally, the clustering is the process of grouping nodes based on different criteria to save energy [13] and helps in the effective management of the available resources of all the nodes. These nodes can be homogeneous, identical and are equipped with the same on-board components, or heterogeneous, the nodes differ from each other and have different on-board equipment.

So far, in many proposed clustering algorithms, the principal goal was to extend the network's lifetime. These algorithms still require improvement. In this work, a clustering algorithm is proposed and tested to demonstrate its efficiency in energy management. The proposed scenario is where a network composed by N heterogeneous UAVs fly over an area to locate M targets simultaneously. These targets can be objects or humans and can be moving or at fixed position. Due to cost considerations and energy constraints, each UAV cannot be equipped with multiple sensors and execute a multi-sensor data fusion process. Indeed, each UAV of this work is equipped by a localization sensor and a camera to detect the target. The available localization sensors used are the global positioning system (GPS), the initial measurement unit (IMU) the light and detection radiation (LiDAR) and the barometer [14]. The GPS is a worldwide navigational system that consists on a constellation of twenty-four flying satellites or more, regularly distributed in a total of six orbits, each satellite circles the planet twice a day [15]. The IMU is a device that consists of a combination of gyroscopes to measure angular rate and accelerometers to measure force [16]. The LiDAR is a method of range determination using a laser and by measuring the time takes the reflect light to return to the receiver [17]. The barometer is an altimeter that measures an object altitude based on the Atmospheric pressure [18]. The UAVs can communicate between each other and exchange different information when needed. The different information provided by the sensors are used to localize the target via a multi-sensor localization process. In this article, the nodes are divided into clusters; each cluster is responsible of the localization of one target and has a master that executes the process of multi-sensor data fusion localization. All the clusters are used to efficiently achieve the mission of multi-targets localization at the same time. The key contributions of the present work are, the proposition of a new UAV's clustering algorithm that helps in the energy management and also the simulation of a real FANET's application to test the algorithm's efficiency.

The reminder of this paper is structured in the following way. The second section reviews some relevant related research works. The third section describes the proposed energy efficient clustering method and presents the algorithm. In the fourth part a simulation is done and the outcomes obtained demonstrated the performances of the suggested method. Finally, the fifth section is a summary of the work and presents the future steps.

2. RELATED WORKS

Before presenting some available related works, the benefits of using FANETs and energy-efficient management should be discussed. By offering a robust communication between the UAVs, such networks achieved success in a variety of civilian and military domains in particular public safety, surveillance, communication, and agriculture [19]. Compared to the different types of ad hoc networks, for instance MANETs or VANETs, FANETs are known for their low time to complete some tasks and their high scalability Figure 1.

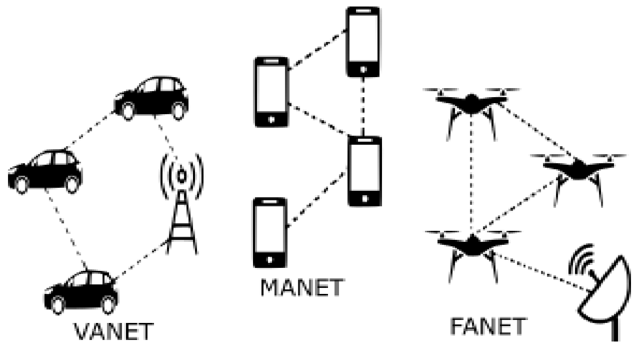


Figure 1. MANET, VANET, and FANET

In some cases of use, the overall cost of achievement of a mission is reduced and more reliability is provided. By connecting FANETs to existing infrastructure networks like cellular and mobile networks, the new generations' technologies are expected to offer enhanced services relating to coverage data rates. As an example, a system for internet of thing (IoT) and UAV integration named IoLoUA is presented in [20]. The system manages the UAVs that fly in low altitude initially used to surmount the flaws in the existing IoT infrastructures. Srivastava and Prakash [21] discussed the role of antenna in FANETs. In fact, the use of directional antenna addresses the special characteristics of the flying network. This type of antenna extends the radius of the communication within the flying nodes and the ground. Because of the advances in UAV related technologies, they were combined with other technologies to provide improved solutions in different domains like health monitoring. Kumar *et al.* [22] developed SF-GoeR, an emergency information dissemination protocol used to immediately transfer a patient health data to a medical professional. A wireless body sensor network collects the needed information and a network of UAVs forward this information to a specialist. The performances of the protocol were tested and compared to existing approaches. Wang *et al.* [23] presented a cluster head election method assisted by the use of an UAV for WSN. In the proposed method, one UAV is used to collect the sensors' remaining energy witch help in the election of the different heads. The use of the UAV guarantees the exclusion of any compromised node. The outcomes of the simulation demonstrate that the proposed framework decreases the sensors energy consumption and extends network's lifetime.

For networks, an efficient management of the energy maximizes the life of the nodes, in FANETs especially, the nodes have a limited flight time because they are energy independent (not attached to a continuous source of energy). Indeed, the power sources on an UAV are for the most part batteries, solar power and fuel cells, each with its advantages and also disadvantages. Furthermore, hybrid systems can be used and the experiments showed that they tend to offer good advantages over all the other energy sources powering techniques [24]. Different works of topology management and clustering are available in the literature especially for WSN. A WSN is a system of sensors, homogeneous or heterogeneous dispersed in an area and used to collect physical information for monitoring or control. The main difference between a WSN and a FANET is that for the first, the nodes are stationary and in the second, the nodes are moving [25]. Shahraki *et al.* [26] reviewed the existing WSN clustering techniques, classified and grouped them on the basis of the clustering objectives. Their work provided valuable insights for clustering techniques design in all ad hoc networks. Clustering techniques are generally known for their energy consumption improvement. Additionally, these techniques may resolve diverse networking difficulties like the security problems, the mobility management, and the quality of service.

A clustering and master election algorithm is introduced for homogeneous UAVs [27]. The proposed algorithm depends on a consensus process. All the nodes have similar communication capacity and distance. Once the leader is selected, it can integrate the information from the other nodes like the computation, the storage resources, and the communication. The leader also coordinates the UAVs within its cluster in order to achieve more complex tasks. Using a simulation platform, the authors repeated the experiment to prove the feasibility of the method and to identify the main characteristics of the algorithm (scalability, high robustness, and adaptability). A location routing protocol, assisted by a link-optimized cone, for FANETs is presented Kumar *et al.* [28]. By selecting relay flying nodes from the cone-shaped request zone, the overhead is reducing and the stability is enhanced. The principal motivation of LoCal is to reduce link failures along with route breaks. The routing performances were compared with other routing techniques based on important indicators like energy consumption, overhead, life-time and delay. Saleh *et al.* [29] propose an energy-aware clustering algorithm called (EHEARA) that depends on solar energy harvesting scheme and a dynamic clustering function. The proposed algorithm extends the wireless networks lifetime by an efficient balancing of communications between the nodes. Compared with other clustering algorithm, the efficiency of the algorithm was proved via simulation. Mansour *et al.* [30], proposed Cross-Layer & Energy-Aware AODV (CLEA-AODV), a routing protocol for FANETs composed by the three main sections AODV routing, cluster master selection based on glowworm swarm optimization (GSO), and cooperative MAC. The protocol enhances the network performances for both the data and the network layers by maintaining the connectivity and reliability. For the CH selection model, the residual energy and the calculated luciferin value via GSO are used. The simulation evaluation demonstrated the effectiveness of the proposed approach.

Research by Bharany *et al.* [31], first employed a moth flame optimization algorithm for the deployment of the nodes and the network. Second, they presented a clustering approach based on the variation of the K-Means Density for the choice of the masters. In this variation, the suggested algorithm takes into consideration a single original parameter that is the neighborhood's degree in addition to two factors the level of energy along with the distance. The moth flame optimization algorithm is inspired by the navigation of moths, flying insects that, during their night flight, manage to keep a fixed angle toward the light source (the moon). Through the experiments, they proved that the method the authors propose presents an efficient energy consumption and a well time in establishing clusters. Kumar *et al.* [32], modified the process of route discovery in the location-aided routing (LAR) for FANETs to propose 3DC-LAR (3D cone-shaped location aided routing protocol), a geographic-based routing protocol. Within this protocol, each request zone is a 3D cone shaped to deal with the flying properties of the nodes and reduce the overhead. The simulation outcomes proved that the proposed protocol performs well especially in cases where the nodes mobility is high. Finally, Srivastava and Prakash [33] a survey relating FANETs and its critical aspects is presented with the goal of highlighting the promising future of FANET. The points discussed are mainly the architecture, the possible communication, the models of mobility, and the specifications. Through their article, the authors encouraged the researchers to work in this particular area to approach better results.

To conclude this section, through their works, researchers proved that clustering ameliorates the nodes' energy together with increasing the lifetime of the network. Actually, by determining the different clusters and their cluster heads, the energy is well managed because only cluster heads take on the most energy consumption tasks. By clustering, the distance of data transfer is reduced and so the amount of energy used.

3. METHOD

The clustering is the action of grouping nodes and managing their resources for the purpose of improving the network efficiency. Indeed, some nodes composes each cluster and each member has a responsibility, a mission. Cluster heads or masters are the nodes responsible of the management of the members and the executing of the network overall process. In some types of ad hoc networks, one or more base stations are used as gateways or to process nodes and clusters are generally created based on distances and angles. In our case, the network would be used in an area where there is no per-existing infrastructure (no base station or no central authority), in an area that human can difficultly reach. After a natural disaster, for example, to localize possible victims.

NUAVs compose the proposed network. With the goal of improving the network's efficiency and the nodes' lifetime, the UAVs are divided into clusters beforehand. Different clusters are created and each cluster is responsible of the localization of one target. This localization can be done via a multi-sensor data fusion process that is described in next. The available localization sensors are the GPS, the IMU, the LiDAR and the barometer. It is clear that the output of the first two sensors is a vector position composed by three coordinates and that the output of the other two sensors is only one coordinate. The vector state of a target is its position in the 3D area; this position can be expressed by the three geographic coordinate's latitude and longitude and elevation.

With the intent of decreasing the number of sensors used in the network, each node has one of the four used localization sensors (GPS, IMU, LiDAR, or Barometer). Moreover, another sensor is used, a camera to detect the target rapidly, however not all the nodes are equipped with it to reduce the network's cost. Different techniques of detection via cameras exist in the literature. Chapel and Bouwmans [34], reviewed the techniques of detection of objects in motion that use a moving camera. They also classified them into eight different approach groups based on the kind of background representation selected to solve the problem. The approach groups are as: dual cameras, subspace segmentation, plane+parallax, panoramic background subtraction, split image in blocks, multi planes, motion segmentation, and motion compensation.

3.1. Clusters formation

Each node in the FANET is identified by two digits: the first is an id i and the second is a parameter j that indicates the type of sensor the UAV has on-board. Every node is identified by Ui, j where i=1,...,N and j=1,2,3,4: 1 for the GPS, 2 for the IMU, 3 for the LiDAR and 4 for the Barometer. The clusters must have different types of nodes, the clusters are composed by nodes that do not all have the same sensors on-board. This configuration is used to improve the mission efficiency also to reduce the overall time.

Each cluster is composed by MUAVs where M<N. Different nodes combinations can be formed; it mainly builds on the number of the nodes constituting the network and the number of the different sensors available. But for all scenarios, the following statements must be respected:

- The maximum number of clusters that can be formed depends on the number $\Sigma U_{i,1}+U_{i,2}$
- The maximum nodes number in a cluster is four nodes for an efficient resources management
- At least three different sensors must compose a cluster (to increase the data accuracy)
- Within the three nodes, at least one has j=1 or j=2, it means the information the senor give has three coordinates. The reason for this occurrence is to localize the target in three dimensions

An example of groups formed is given in the next part. To sum up what has been stated, the process of clusters formation is unique to each scenario. The cases where the nodes of cluster would be ungrouped and return to the ground are given in next. In our proposition, a node cannot join a cluster during the operation because the number of nodes that will fly is predefined before the mission begin and all the nodes are member of a cluster and participate to the process.

3.2. Master election

After the cluster's formation, a master is elected in each cluster. In addition, to avoid the special cases where during the flight, the master is unavailable, a backup master is also elected. In the network, the nodes of the different clusters are heterogeneous UAVs that do not have the same capabilities. The master node (M) is the node with most available energy and the backup master node (M_B) is the node with second most available energy. In the case of where two or more UAVs have the same available energy, the choice of the masters is based on the id. Only the id and the available localization of the nodes are considered in the process of masters' election, the second index that indicates the type of sensor is not used in the following process. To elect the master, each node executes the algorithm 1. By executing the algorithm 1, the backup master is also elected. Via Algorithm 1, within a cluster, each node compares its energy with the M-1 neighbor nodes; if its energy is bigger, it elects itself as the master, if its energy is lower, it participates in the election of the backup master and in the case, it has the same energy as the other node, the master is the node with the upper id.

The terminology used in Algorithm 1 is as:

- ex: the energy of node with id=x
- eyx: the energy of node with id=y that node id=x received
- M: the master
- MB: the backup master

Algorithm 1. Master and backup master elections

```
for i = [1,…,M] do
     for k = [1,…,M]-i do
if ei < eki then
   go to 15
else
     if ei > eki then
      go to 14
     else
          if ei = eki then
              if i < k then
```

```
                go to 15
             else
                go to 14
M = node with id i
for l = [1,…,M]-{i,k} do
if e_k < e_li then
   go to 26
   if e_k > e_li then
       go to 25
   else
       if e_k = e_li then
          if k < l then go to 26
        else
           go to 25
M_B= node with id k
terminate
```

4. RESULTS AND DISCUSSION

For the simulation, we use the platform OMNeT++ [35], a discrete event simulator (DES) that is modular and based on a C++ simulation framework and library. It is a free simulator that helps researchers and can be used to build network simulators. The INET Framework extension was also used because it helps features models for wireless radio communication. This extension of OMNeT++ especially helps in modeling the spatial relations of mobile nodes.

Using the simulator, a FANET composed by one hundred nodes (N=100 UAVs) is created. We suppose that each node is equipped with one localization sensor (GPS or IMU or LiDAR or Barometer) with the goal of reducing the cost of the network. The flying nodes in use are as:

– 27 nodes equipped with a GPS (j=1)
– 19 nodes equipped with an IMU (j=2)
– 21 nodes equipped with a LiDAR (j=3)
– 33 nodes equipped with a Barometer (j=4)

In the proposed method, the step of clusters creation is done before the beginning of the mission. Table 1 represented the most important parameters in use for the simulation.

Table 1. Simulation parameters

Parameter	Value
Simulator	OMNeT++
Simulation area dimensions	500*500*100 (m^3)
Nodes number	100
Mobility model	RWP
Node speed	0-20 m/s
Pause time	0 s
Size of packets	1,024 bytes
Transmission range	50-300 m
OSI fourth layer protocol	UDP
Physical layer	MAC
Data rate	2 Mbps
Radio range	250 m
Simulation duration	300 s

By respecting the rules defined in the previous section, thirty-one clusters to localize thirty-one possible victims are created as:

Clusters with three nodes:

– 3 clusters composed by one GPS, one IMU, and one LiDAR
– 5 clusters composed by one GPS, one IMU, and one Barometer
– 2 clusters composed by one GPS, one LiDAR, and one Barometer
– 2 clusters composed by one IMU, one LiDAR, and one Barometer
– 7 clusters composed by one GPS, and two Barometer
– 3 clusters composed by one GPS, and two LiDAR
– 1 cluster composed by one IMU, and two Barometer
– 1 cluster composed by one IMU, and two LiDAR

Clusters with four nodes:

– 2 clusters composed by one IMU, one GPS, and two LiDAR
– 3 clusters composed by one GPS, one IMU, and two Barometer
– 2 clusters composed by one GPS, one IMU, one LiDAR, and one Barometer

Then for each cluster, the master and the backup master are elected via algorithm 1. Figure 2 shows one of the clusters formed by four nodes: master, node1, node2, and node3. With the simulation platform, we first, initialize the environment by creating a FANET composed by 100 UAVs distributed in the area as determined. The proposed method was then compared with the GSO [36] algorithm and evaluated in terms of energy consumption, that we assume the most important criteria for that type of work. Introduced in 2005, GSO is an algorithm that is based on swarm intelligent to solve optimizing problems in the robotic area, it can be used to optimize localization multiple sources problem. The simulation also involved the time it takes for a cluster to localize a specific possible victim. Figure 2 shows one of the created clusters formed by four nodes: master, node1, node2, and node3.

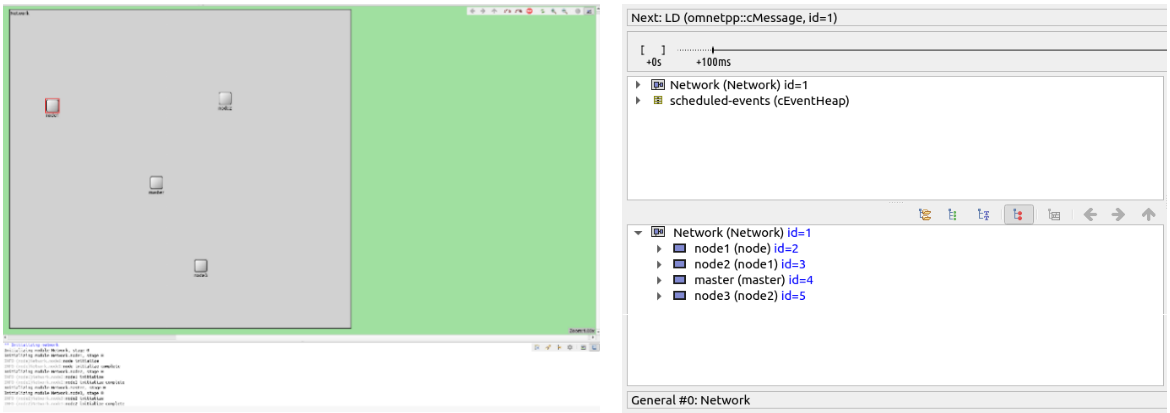


Figure 2. A cluster composed by four nodes, captures from OMNET++

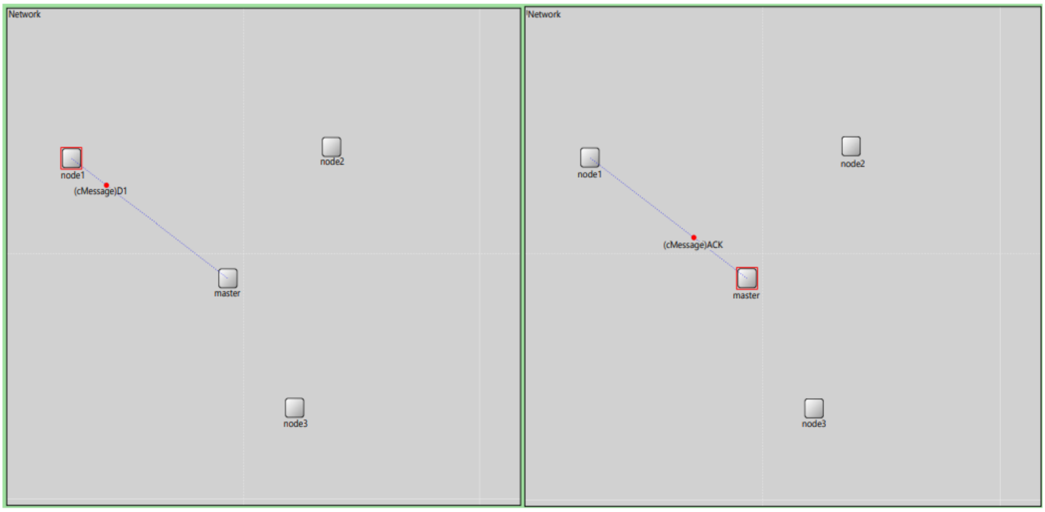
At the beginning of the simulation, the different nodes fly in the selected area with respecting cluster. As soon as a target is detected, the cluster hovers over the area, the different nodes of the cluster determine the data needed by using their inboard sensor. In our scenario, we suppose that the data needed is the target localization data.

After that, the next actions happen, in the following order:

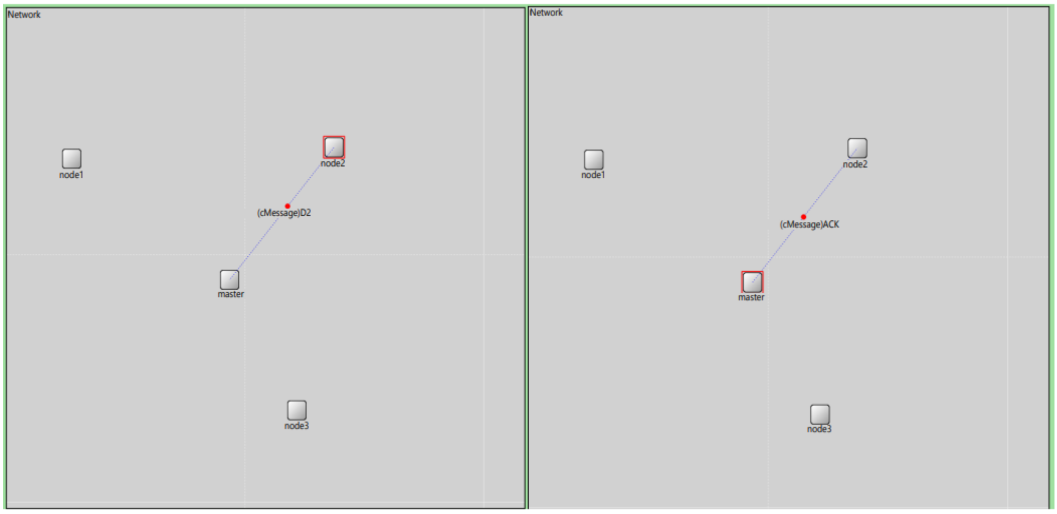
– Node1 sends the data collected (D1) to the master then the master sends back an acknowledgment (ACK) that indicates it received the data as shown in Figure 3(a).
– Node2 sends the data collected (D2) to the master then the master sends back an acknowledgment (ACK) as shown in Figure 3(b).
– Node3 sends the data collected (D3) to the master then the master sends back an acknowledgment (ACK) as shown in Figure 3(c).

Therefore, all the nodes in every cluster send their data to the master. To test the performances, we set the area of search and we roll the simulation for 300 s. We first assumed that at t=0 s, each node of the 100 used nodes has an energy of 1.2 K Watt. Then we tracked the nodes remaining energy throughout the simulation. Finally, we calculated the average remaining energy obtained after the simulation and we did the same process with the GSO algorithm. The obtained results are displayed in Figure 4.

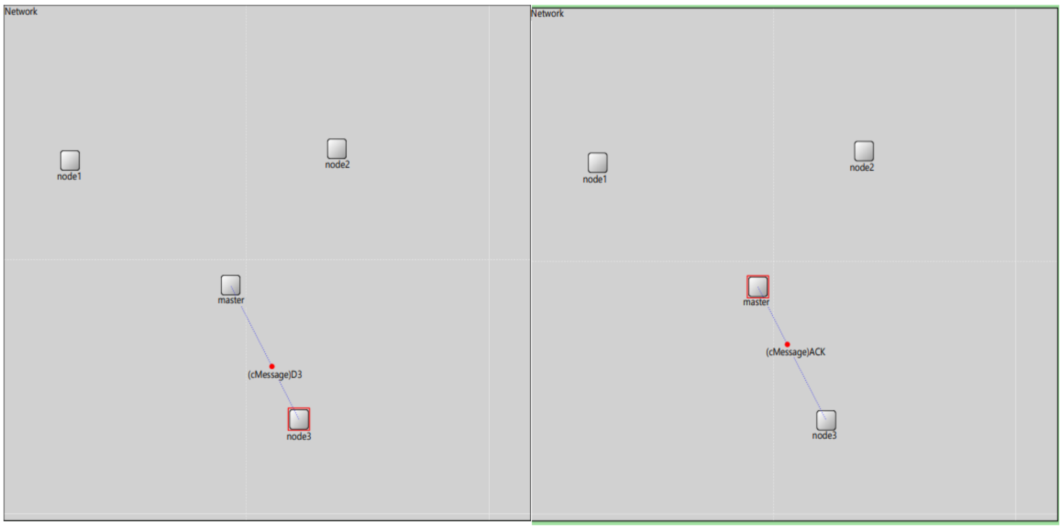
Based on the results obtained in Figure 4, we can see that the proposed algorithm consumed less energy than GSO algorithm. Then we tested another important parameter that is the time that a cluster took to detect a target. To do so, we first have to present the further work done. So, after the master receives the localization data from the different nodes, it executes a multi-sensor data fusion process and retrieves an accurate localization of the target. This process is the process of combining information from different sensors to provide an accurate and robust information. Generally, Data fusion can be applied in many fields mostly robotics, localization, and environment mapping. The applied data fusion process is constituted by a particle filter. Introduced in 1993, the particle filter is a numerical approximation to the nonlinear state estimation problems [37]. The solution is based on a nonlinear Bayesian filtering solution. The Bayesian filtering is built on Bayes' theorem that describes the probability based on prior experience and knowledge.



(a)



(b)



(c)

Figure 3. Nodes communication with the master: (a) node1 communication with the master, (b) node2 communication with the master, and (c) node3 communication with the master

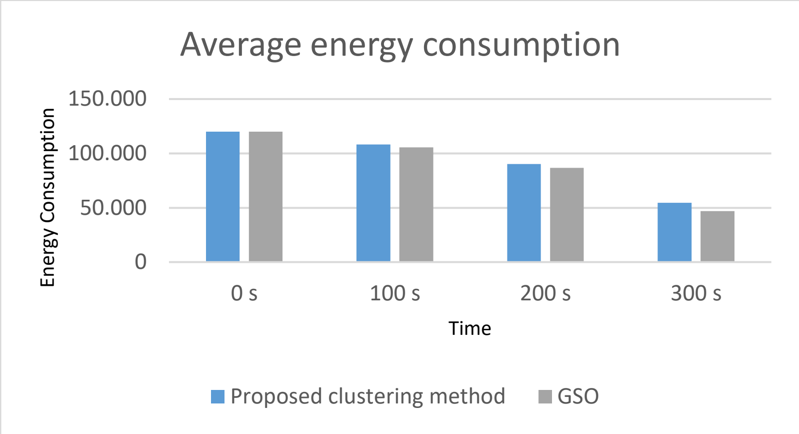


Figure 4. Average energy consumption for the proposed scenario

In the same way, each cluster localize one target: each master collects gathers the needed from the other nodes constituting the cluster and determines the target's localization. All the data from the different master is then sent to the ground station that will use it for a precise purpose. The different masters have an already predefined optimal route to the ground. To save resources, only the masters participate in the transfer of the data collected.

The nodes are assumed to have a speed of 20 m/s with no pause time. Via the simulator, we calculated, first, the time it took the cluster presented in the example to localize a target situated at the coordinates (120, 50, 25). Knowing that the cluster began the search at t=0 s and was the first to detect the target, the time obtained was 65 s.

4.1. Discussion

Based on the simulation, the proposed algorithm outperforms GSO algorithm in term of energy consumption. In addition, with our method, the overall time of the mission of localization of M targets, in the same time, is less than methods where the clusters are created during the flight. This can be explained by the time saved when creating different clusters before the beginning of the mission. Compared with the majority of the available methods in the literature, the life time of the nodes is better based on the assumptions that no energy of creation of the clusters are wasted during the flight and the master. And also, the node that will do the majority of the process, is the node with the most available on-board energy.

5. CONCLUSION

Papers In this work, we proposed a clustering method for heterogeneous nodes of a FANET. Every node in the network is equipped with one localization sensor; four sensors are used (GPS, IMU, LiDAR, and Barometer). The nodes are divided into clusters before they begin their mission and each cluster is responsible of the localization of one target. For each cluster, a master is elected. The master is the UAV with the most important energy and he is responsible of the main activity in the mission. To anticipate possible unavailability problems, a backup master is also elected. During the flight, the master collects the information from the different nodes, after it determines an accurate localization data of the target via a multi-sensor data fusion process. The simulation outcomes proved the method's efficiency and the extended life of the network. The technological advances on UAV increased the use of FANETs and their different limitations make them an interesting field of research. Further work is certainly required to validate the results. Therefore, further research is to search for a funding opportunity that would mainly help in the effective realization and the testing of the proposed method in real conditions. That will help us improve what was proposed.

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