

Performance analysis on self organization based clustering scheme for FANETs using K-means algorithm and firefly optimization

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ABSTRACT

With the fast-increasing development of wireless communication networks, unmanned aerial vehicle (UAV) has emerged as a flying platform for wireless communication with efficient coverage, capacity, reliability, and its network is called flying ad-hoc network (FANET); which keeps changing its topology due to its dynamic nature, causing inefficient communication, and therefore needs cluster formation. In this paper, we proposed a cluster formation, selection of cluster head and its members, connectivity and transmission with the base station using the K-means algorithm, and choice of an optimized path for transmission using firefly optimization algorithm for efficient communication. Evaluation of performance with experimental results are obtained and compared using the K-means algorithm and firefly optimization algorithm in cluster building time, cluster lifetime, energy consumption, and probability of delivery success. On comparison of firefly optimization algorithm with K-means algorithm, i.e., K-means algorithm results proved than without firefly optimization algorithm, better in terms of cluster building time, energy consumption, cluster lifetime, and also the probability of delivery success.

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1. INTRODUCTION

Technical progress in the area of flying platforms emerged unmanned aerial vehicle (UAV) as a promising technology. UAVs have various applications in the field of military, navigation, surveillance, broader supervision, medical supply, control, rescue operations, an inspection of hazardous events, disaster management, monitoring, relay network, and communication [1]–[7]. Not only do these UAVs have capabilities in sensing, storage, and processing, which makes it an intelligent system for communication, the internet of things (IoT) [8]–[11], and the establishment of a smart city. These IoT services include package delivery, tracking, and search operations. The unique characteristics of UAVs, reliability, survivability, scalability, flexibility, cost-effectiveness [12], [13] make them an efficient choice for IOT, and communication.

UAVs are commonly called drones. The network of UAVs is called flying ad-hoc network (FANET) [14]. It is one step up-gradation towards wireless communication technology. Still, a problem in this advanced technology arises due to its mobile nature of communication that causes a change in its network topology that

results in problems in their connection maintenance and hence results in inefficient communication. The most commonly adopted solution to this problem is clustering [15] and opting optimization.

Clustering is an unsupervised technique to divide the network into groups [16]. Each cluster consists of a cluster head (CH) and cluster members (CMs). The selection of CH plays a vital role in cluster maintenance and its operation. All the inter and intra operations in clusters, such as routing procedures of the cluster, a connection of cluster and base station, and removal of the dead node, are performed by the CH. Therefore, the election of the CH is done with various parameters. For determining the fitness function of a cluster, different clustering schemes have been proposed by the authors.

Yang [17] proposed a routing mechanism for wireless sensor networks (WSNs) and UAVs. The network is divided into clusters and sensor nodes. Each UAV knows the position of their CH, and their routing mechanism is based on ant colony optimization (ACO). The behavior of ants inspires this mechanism in searching for the shortest path to their destination. Maistrenko *et al.* [18] proposed a routing mechanism inspired by the behavior study of ants for optimal pathfinding. This mechanism is inspired by two types of behaviors of ants—forward and backward. In forward, ants, in search of their food, keep on secreting pheromones in their way, and backward ants follow the path with the highest pheromones as an optimal path to their search.

Al-Aboody and Al-Raweshidy [19] proposed a multilevel routing mechanism for the election of CH. It is of three-level process. In the first level, the CH election is based on the residual energy, distance from the ground control station and energy. The second level is an election of CH based on the grey wolf optimization (GWO) algorithm, the number of UAVs in its neighborhood and its residual energy; the third level is the tree-based approach for CH selection. Khan *et al.* [20] proposed a clustering scheme for the dynamic nature of UAVs, causing instability in the routing process of FANET. This paper presents a bio-inspired clustering scheme, a hybrid of glowworm swarm optimization (GSO) and Krill Herd (K.H.). Cluster head selection is proposed based on the GSO algorithm and cluster management is proposed using K.H. Genetic operators are used for determining the position of UAV, path detection based on residual energy, number of neighboring UAVs, and distance between UAVs. Performance is evaluated in terms of quality-of-service parameters as cluster building time, energy consumption, cluster lifetime, probability of delivery success with GWO, and ACO.

Khan *et al.* [21] proposed that the mobility and changing topology of UAV create communication issues for efficient communication. GSO is used for cluster formation and maintenance. Cluster head station and its connectivity with ground control station are maintained using GSO and route mechanism based on neighborhood, residual energy, and position of UAV.

The above-proposed clustering optimizations algorithms performed well. With motivation from these, this paper has contributed to: i) we propose a new clustering mechanism in FANET using the K-means algorithm and firefly optimization algorithm, ii) we propose a K-means algorithm for cluster formation, selection of CH, CMs, and performing routing operation between nodes and ground control station (GCS), iii) we propose a novel optimization technique for routing using a firefly optimization algorithm, and iv) we propose a comparison of performance efficiency of the proposed k-means algorithm and firefly algorithm (FFA) for routing mechanism in terms of quality of service (QoS) parameters of energy consumption, cluster building time, cluster lifetime, and probability of delivery success.

The rest of the paper is tabulated as: section 2 explains the k-means algorithm for cluster formation, cluster management, and routing between nodes. Section 3 describes the optimized technique of routing using firefly optimization. Section 4 provides an explanation of the evaluation of FANET using k-means and firefly optimization. Section 5 concludes the paper.

2. K-MEANS ALGORITHM

The K-means is the most straightforward and unsupervised clustering algorithm [22]. It is a method to divide the network into groups called clusters consists of CH and CMs. This algorithm is a method to group data into clusters based on Euclidean distance between data members and centroid consists of various steps: i) from multiple nodes randomly select a UAV called CH of a cluster and ii) calculate the Euclidean distance of CH with every node. Distance is calculated by (1):

$$(p_k, q_j) = \sqrt{\sum_{i=1}^d (p_{ki} - q_{ji})^2} \quad (1)$$

where, p_k denotes k^{th} data member and q_j denotes centroid of cluster j , i denotes the number of data members.

- Nodes with a smaller Euclidean distance from CH become members of a similar cluster.
- Calculate the mean of updated cluster members of a cluster.

- If the calculated mean is same as that of CH of the cluster, then iteration stops and CH gets updated.
- If the difference between mean and CH is there, then number of iterations continues till there is little change in CH after each iteration, or no change.

Similarly, CH and CMs are elected in each cluster of FANET structure from many UAVs. In Figure 1, the number of initialized nodes are shown, cluster formation, and selection of CH and CMs take this node's place using the above-stated standard K-means algorithm. In the Figure 2, initialized nodes are divided into clusters. Each cluster node is shown in different colors to signify other cluster formations in a region using a K-means algorithm.

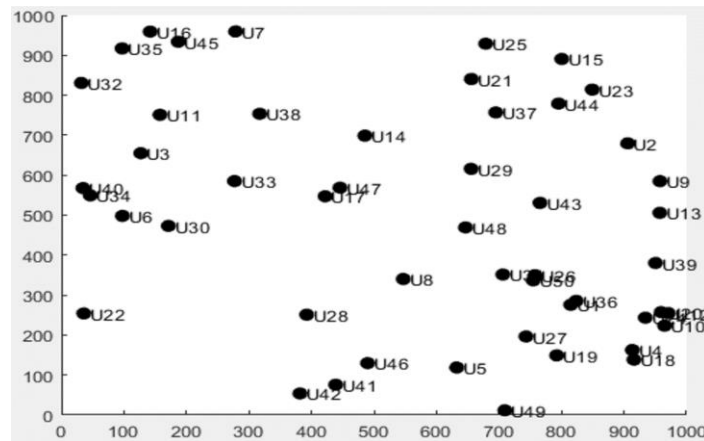


Figure 1. The number of initial nodes

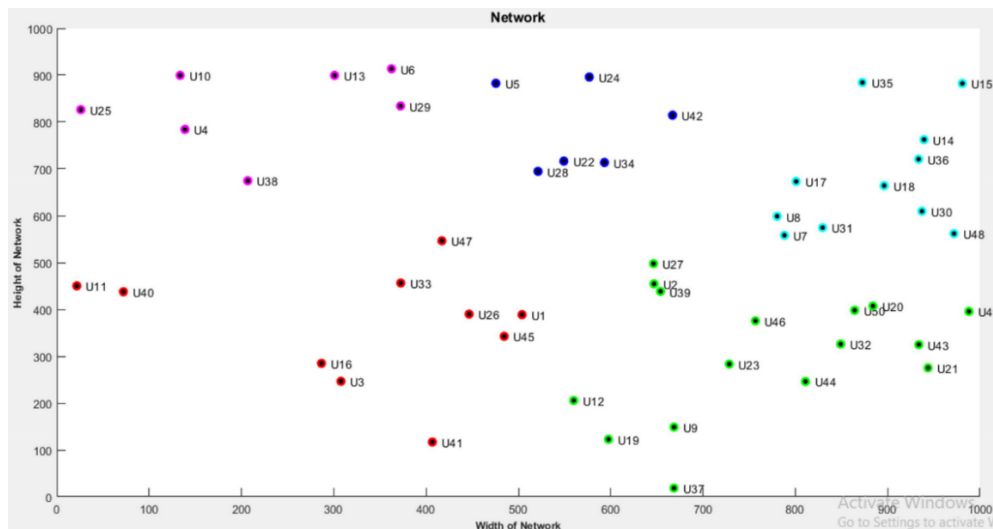


Figure 2. Formation of cluster using K-means algorithm

In Figures 3 and 4, the cluster head is selected based on the above-stated rules of choosing the K-means algorithm and connected with cluster members. The selection of cluster head is an essential parameter in cluster operation for data transmission from a cluster to other clusters. During transmission, data from the source cluster member transmits to that cluster's cluster head. The cluster head of the source cluster sends the data to the destination cluster head and the cluster head to the respective destination. That is how transmission in FANET operation takes place. The transmission of data from cluster to base station also similarly takes place. Every cluster head of the cluster is connected with a base station for efficient communication. Both Figures 5 and 6 show all cluster heads' connections with the base station for their efficient transmission besides the effective communication of all clusters with the base station. From cluster formation to connectivity with the base station, this paper achieves using the K-means algorithm can be seen in Algorithm 1.

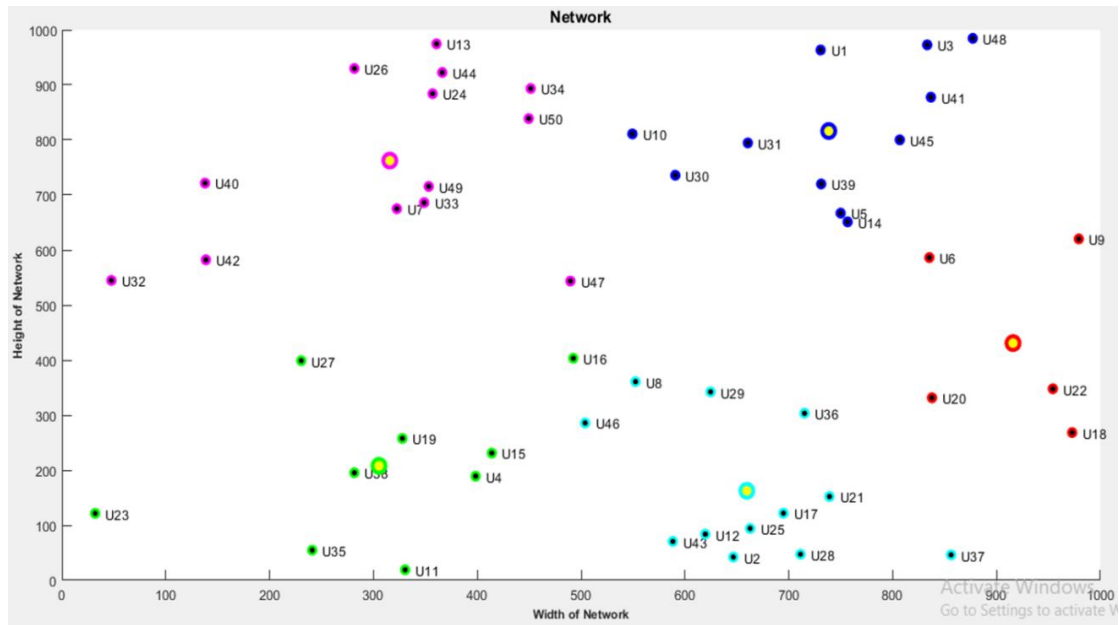


Figure 3. Selections of CH and CMs

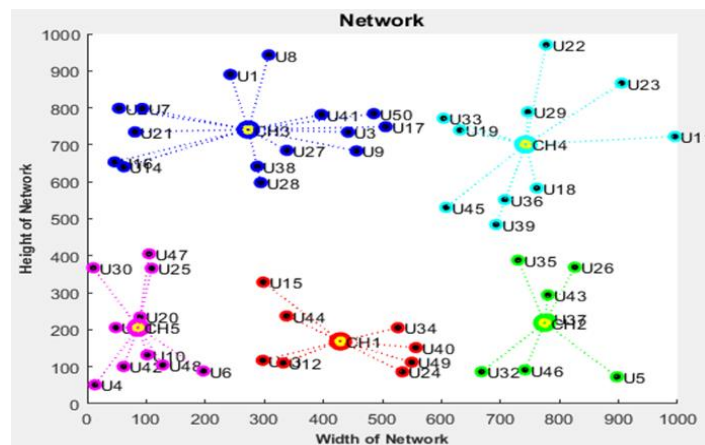


Figure 4. Connectivity of CH and CMs

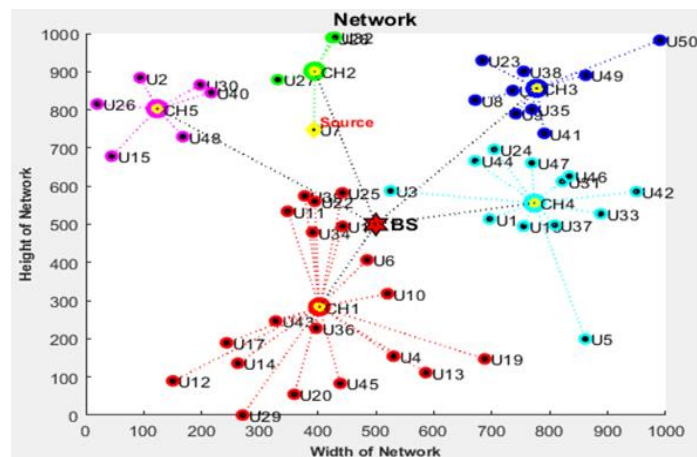


Figure 5. Connection of all CH of clusters with base station (BS)

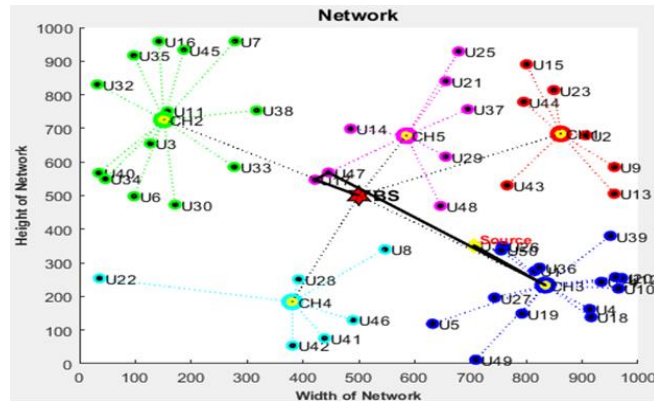


Figure 6. Transmission of data from source to BS.

Algorithm 1: Cluster formation and routing using K-means algorithm

```

Initialize number of nodes, i = 1,2,..., n
RTR <= Request to reply
Dest <= To specify destination found
Check pt <= no of times check nodes to reach destination
For (select CH of every cluster)
    While (connect every CH with its nodes)
        Locate GCS location
        For (connect GCS with every CH and other GCS)
            Locate radius of GCS and source node position specify number of check points
        For 1: n, for all n nodes
            Check (distance of source node with every node in its specified range to reach
            destination)
            If (RTR==1) // connection set up from source to destination
            Else
                Check (every node in range to reach destination)
                If (packet reaches destination)
                    then Dest = 1;
                Else
                    check till reaches checkpoint
            End
            Feed the sequence of intermediate nodes from source to destination.
        End
    End
End
End

```

3. FIREFLY OPTIMIZATION ALGORITHM

The firefly optimization algorithm is a subset of the swarm intelligence (SI) algorithm. These algorithms are inspired from natural phenomena and characters as humans, ant, bee, birds, worms, flies, termites, and fishes. Inspired by these biological agents, there are multiple optimizations available there: particle swarm optimization, ant colony optimization, cuckoo search optimization, glowworm swarm optimization, and firefly optimization [23], [24]. In this paper, we will discuss firefly optimization. Before that, we will discuss the origin and drawback of optimization that leads to this novel optimization and how it overcomes its flaw.

The authors developed the firefly optimization algorithm in 2007 and 2008 [25]–[27]. It is inspired by the natural phenomena of flashing patterns and the behavior of fireflies. It originated to overcome the drawback of GSO. The flashing behavior of lighting worms inspires GSO [25]–[27]. Each glowworm has its luminescence called luciferin, which decides its current position. Glowworm with lesser luciferin value moves towards a brighter one within decision range, changing its position and luciferin level. A higher luciferin value is closer to an optimal solution that keeps the iteration process on until optimal value. The drawback in this process is its unconstrained functions in higher dimensions.

Firefly Optimization is inspired by winged insects that produce a bioluminescent flash, which they use for communication and attracting prey. It was developed at Cambridge University in late 2007 [28], [29]. Yang made three idealized rules for this optimization: i) fireflies are unisex, and they attract one another regardless of their sex, ii) attractiveness between two fireflies is directly proportional to their brightness and inversely proportional to the distance between them. As the distance increases, their brightness decreases. Thus,

brighter fireflies attract the less bright ones, but if both have the same intelligence, this will lead to the random movement of both the fireflies, and a landscape of the objective functions determines the brightness of fireflies [30], [31]. For n fireflies, the brightness of the firefly i is associated with objective function $f(x)$:

$$I = f(x) \quad (2)$$

It reveals the current position of firefly from the set x_1, x_2, \dots, x_d . Suppose, for two fireflies, m and n namely with their x_m, x_n positions respectively. Their attraction depends upon their quantity of brightness, and some constraints between both of them like the absorption of air and the square of the distance between these two fireflies. Relative distance between these two fireflies is:

$$I_{mn}(r_{mn}) = \frac{I_n}{r_{mn}^2} \quad (3)$$

$$\text{or } I_{mn}(r_{mn}) = I_{mn} e^{-\gamma r_{mn}^2} \quad (4)$$

where I_{mn} is absolute luminescence of firefly m and firefly n , r_{mn} is distance between both fireflies m and n respectively, γ is light absorption coefficient. The attraction between fireflies is represented as:

$$\beta_{mn}(r_{mn}) = \beta_0 e^{-\gamma r_{mn}^2} \quad (5)$$

β_0 firefly attraction at $r = 0$, γ is light absorption coefficient, in many applications, it is generally taken as $[0.01, 1.00]$. Now, firefly n attracted towards firefly m updated its position by the (6):

$$x_n = x_n + \beta_{mn}(r_{mn})(x_m - x_n) + \alpha \varepsilon_n \quad (6)$$

where, $\beta_{mn}(r_{mn})$ is an attraction parameter and $\alpha \varepsilon_n$ is a randomization parameter [32].

3.1. Firefly routing mechanism

In the firefly routing mechanism, the optimal path for data transmission from a source node to a destination is selected using the firefly algorithm. The optimal way comprises judging of failure node that is a node causing delay, more energy consumption, and unsuccessful delivery during transmission by eliminating a node and selecting a course that comprises maximum efficiency using an algorithm. Artificial neural network (ANN) is used for optimizing a path of transmission and ANN inspired by the biological nervous system of the animal brain [33]. In ANN, data transmission takes place by weights, unlike synapses in a biological brain. This system consists of an input layer, hidden layer, and output layer [33], [34]. The hidden layer is used for net computation and producing net input applied with activation function to obtain the actual output. These systems are designed for self-training, implementing and testing processes [35]. This feature of ANN makes it to help optimize a path for data transmission that includes tracing a faulty node by self-learning capability and make corrections in it by selecting the optimal route. It then tests the process, again and again, to analyze whether the process going on should be correct without any amendments. In above-shown Figures 7 and 8, fail nodes are replaced with optimized paths using the firefly optimization algorithm. In this algorithm, faulty nodes are traced, and optimization of the path from source to destination is performed using firefly and ANN techniques of self-training, implementing, and testing process.

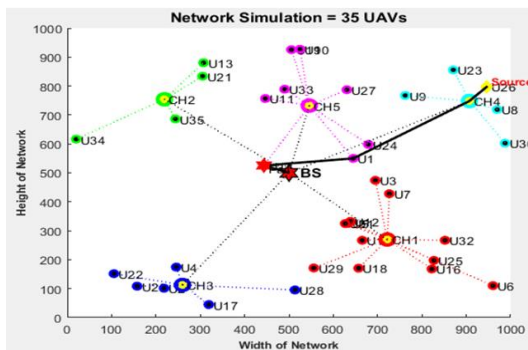


Figure 7. Faulty (fail) node is shown with the red star near BS using ANN

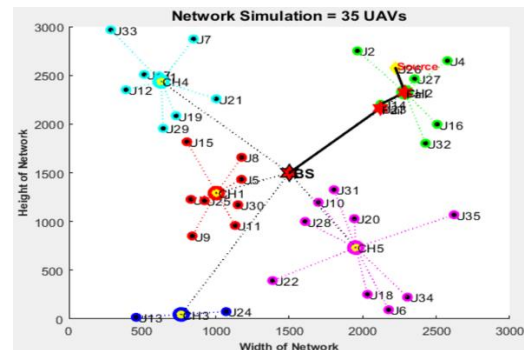


Figure 8. Faulty (fail) node is shown with a red star near source node using ANN

Algorithm 1: Optimization using firefly

```

Initialize the empty list of fail UAV
For (data transmission from source to destination)
    Check if (fail UAV~=source node & fail UAV~= Destination node)
Then (label it as fail)
    fail UAV = fail UAV +1
Update (Transmission path by replacing node)
End

```

4. RESULTS AND DISCUSSION

We discussed the transmission using K-means an optimized path selection using the firefly optimization algorithm. Based on optimized path selection, we will evaluate some QoS parameters using software simulation in MATLAB in terms of cluster lifetime, cluster building time, energy consumption, and the probability of successful delivery and analysis their results on different area sizes.

4.1. Cluster lifetime

Cluster lifetime is the time of a cluster from its formation to its disposition. That is, its selection as a cluster head till it reaches its threshold and selection of new cluster head depending on fitness function of cluster members that complete the requirement of cluster management. In Figures 9 and 10, cluster lifetime is lesser during transmission using the K-means (without FFA) and improved by selecting the optimized path for routing using FFA. So, FFA optimization proved better than without using FFA for transmission on different area sizes.

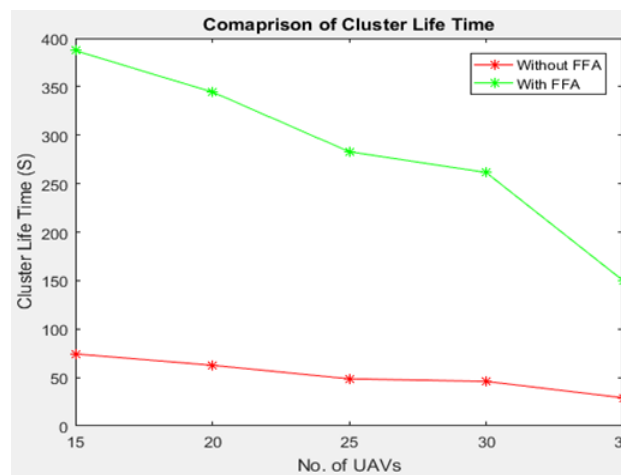


Figure 9. Cluster lifetime vs no of UAVs in grid size 1000x1000 m²

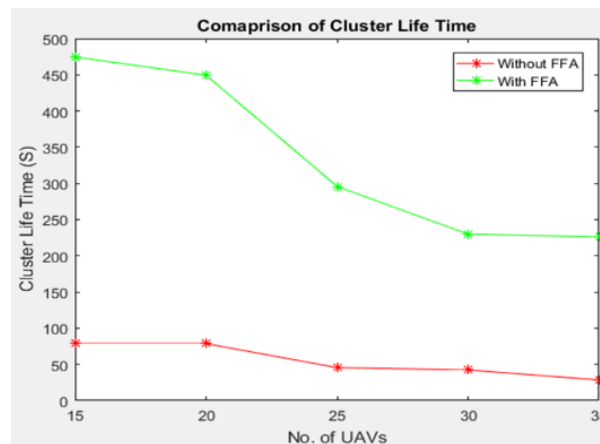


Figure 10. Cluster lifetime vs no of UAVs in grid size 3000x3000 m²

4.2. Energy consumption

Energy is an essential aspect of UAVs. It is an energy consumption from cluster building to its lifetime for performing all UAV operations, for communication, sensing, route selection, rate of successful packet deliveries, transmission delays, and collisions during transmission. Transmitters, receivers, and amplifiers installed also cause energy consumption in the system. On varying area sizes in Figures 11 and 12, energy consumed during transmission using a K-means algorithm (without FFA) is lesser than the energy consumed using transmission using the optimized path of the FFA. By increasing the number of UAVs, energy consumption also increases.

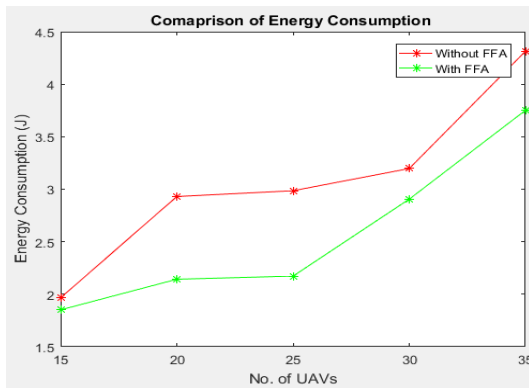


Figure 11. Energy consumption vs no of UAVs in grid size 1000x1000 m²

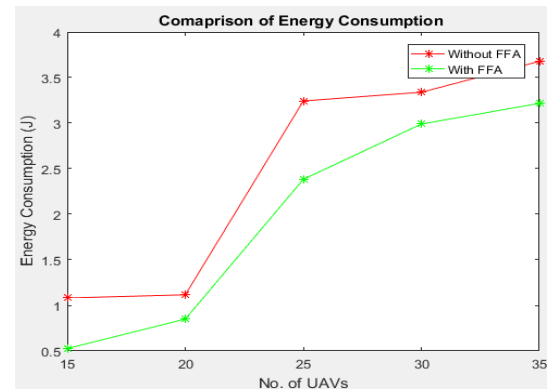


Figure 12. Energy consumption vs no of UAVs in grid size 3000x3000 m²

4.3. Cluster building time

Cluster building time is the time taken for cluster formation, selection of CH and its associated CMs. An increase in the number and energy consumption in UAVs leads to an increase in cluster building time. Low memory and computation power in UAV also affects cluster building time. In Figures 13 and 14, cluster building time is lesser during transmission using the K-means (without FFA) and improved by selecting an optimized path for routing using FFA. So, FFA optimization proved to be better than without using FFA for transmission on different area sizes.

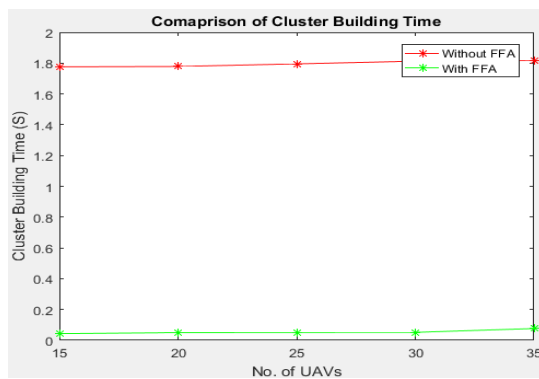


Figure 13. Cluster building time vs no. of UAVs in grid size 1000x1000 m²

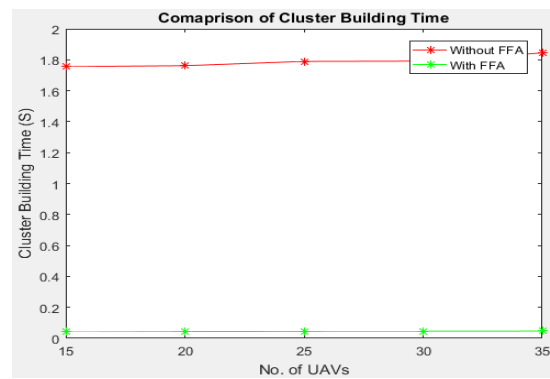


Figure 14. Cluster building time vs no. of UAVs in grid size 3000x3000 m²

4.4. Probability of delivery success

The probability of delivery success comprises of successful transmission of data from source to the destination node without any likelihood of data drop and node failure cases. The increase in the number of nodes results in an increase in network density and a decrease in the data drop ratio. Hence, increase in the probability of delivery success. From Figures 15 and 16, the likelihood of delivery success is more using optimized transmission of the firefly algorithm.

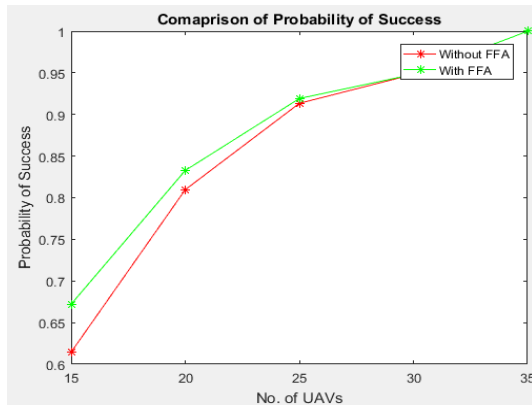


Figure 15. Probability of successful delivery vs no. of UAVs in grid size 1000x1000 m²

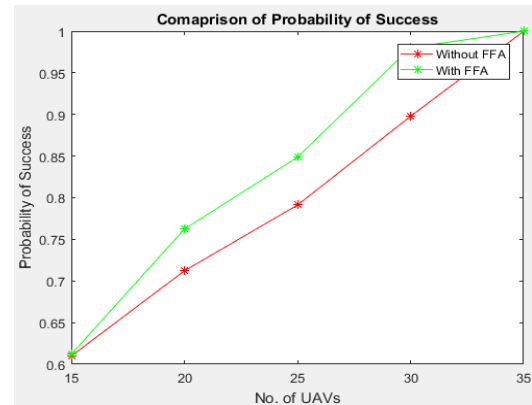


Figure 16. Probability of successful delivery vs no of UAVs in grid size 3000x3000 m²

5. CONCLUSION AND FUTURE SCOPE

In this paper, we have discussed UAV and their applications. Network of UAV called FANET, its changing topology and its effect on communication network calls for the need of clustering. Clustering, using the K-means algorithm, includes a grouping of nodes, selection of CH and CMs of every cluster, and connecting all CHs of the cluster with BS for efficient communication. Furthermore, the transmission of the data source to the destination node using a K-means algorithm, and then selection of optimized path using FFA. Comparing FFA with without FFA (K-means), results proved that FFA is better in cluster building time, energy consumption, cluster lifetime, and probability of delivery success.

In the future scope of this paper, work can be done on an optimized path using FFA. By saving an approach, we can transmit confidential information by using it as a trust management path. Work can also be done to enhance the optimized way every different transmission path can be selected without any chance of failure.

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