Interfrence-Aware Clustering Algorithms for Mobile ad hoc Network

Ant Colony optimization-based Algorithm

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Abstract—**The next generation tactical networks will be based on mobile ad hoc networks (MANETs). These networks require as well a stable clustered network structure as an efficient channel assignment optimization method. Efficient spatial channel reuse provides network scalability and high spectral efficiency. In this paper, a centralized clustering algorithm scheme based on ant colony optimization (ACO) is suggested for forming clusters and assigning channels to clusters. Ant colony optimization (ACO) is used to select the cluster heads in an as advantageous way as possible. A multi-objective function is designed to maximize the stability and scalability, minimize the number of clusters and inter-cluster interference power. The suggested algorithms are evaluated for numerous scenarios. Particularly, the performance of ACO-based clustering algorithm is compared with other clustering algorithms.**

I. INTRODUCTION

Mobile ad hoc networks (MANETs) have crucial roles in the next generation tactical military networks and battlefield communications. Efficient spectrum management is essential to effectively utilize resources, control MANET's topology, and improve the networks' performance [1]. Creating communication hierarchies out of sets of mobile nodes that is referred to as *cluster formation* is one way to manage spectrum. The clustering algorithms partition the network into groups of mobile nodes to provide a well-organized scalable structure for routing algorithms, power control mechanisms and spectrum assignment methods [1]. A common structure for forming a clustered network topology is based on defining three types of nodes: *cluster head, gateway* and *ordinary nodes.* The cluster head, the master of a cluster, is responsible for allocating resources and coordinates the intra cluster communication. The gateway, which is a common node between two or more clusters, provides the connectivity between the clusters. Others nodes are ordinary nodes that determine the boundary of clusters, which is dependent on the transmission range and the node density [1]-[3].

Forming a scalable and stable clustered structure satisfying some constraints e.g., minimizing number of cluster heads, reducing control communication overheads, etc., is an NP-hard problem [4]-[6] that can be handled by using meta-heuristic methods providing feasible solutions in polynomial time. Ant colony optimization (ACO) is a type of meta-heuristic algorithm that has been widely used in wireless communication, in particular Mobile Ad-hoc Networks (MANETs). So far, several ACO-based routing algorithms such as ANT_AODV Ant Colony Algorithm in MANET-Local link repairing of AODV) and POSANT (Position Based Ant Colony Routing Algorithm for Mobile Ad-hoc Networks) [1], [2] have been proposed to provide efficient routing methods for MANETs. ACO has also been proposed as a basis for clustering algorithms. The ACO-based clustering algorithms have shown the capability to provide a scalable and stable clustered network structure [3], [4]. The goal of an interference aware clustering scheme is to address the spectrum scarcity issue by maximizing the spatial channel reuse; an efficient channel assignment method would also necessitate maximizing the spectrum efficiency.

In this paper, we suggest an ACO-based procedure for forming clusters and selecting the cluster heads. The suggested algorithm differs from the previous meta-heuristic clustering algorithms in terms of defining the objective functions and providing a feasible solution for a NP-hard problem. Thus the main contribution of this paper is to design a multi-objective function and proposing an interference aware clustering algorithm.

II. RELATED WORKS IN CLUSTER FORMATION

In MANET, a clustering algorithm divides a flat network topology into a set of connected clusters that cover all mobile nodes in the network. Generally, clustering algorithms have been proposed to increase the manageability and scalability of MANETs.

Simple clustering methods are 'identity based clustering' [6] algorithms (e.g. Lowest-ID and Max-min d-cluster algorithms), which selects the cluster heads on the basis of the node's ID. These algorithms aim at reducing the control communication overhead in the network and maximizing the stability of the clusters in terms of prolonging the lifetime of cluster heads [6]. The highest connectivity clustering (HCC) algorithm, which is a type of ‘connectivity-based clustering’ [6] algorithms, is another simple clustering algorithm with a similar objective as LID; however, it uses the node’s degree to form the clusters [6]. Other instances of connectivity-based clustering algorithms have objectives to satisfy load balancing constraints or minimize the number of cluster heads (e.g. minimize the dominating set) [4]. Clustering algorithms that form the clusters by using mobility metric (e.g. mobility based metric for clustering (MOBIC)), are referred to as mobility-aware clustering methods [7]. The main objective of these algorithms is to stabilize the intra-cluster connections or minimize the rate of re-affiliations [7]-[8]. In the combined–weight based clustering method, a weight, which is defined as a summation of several metrics, is assigned to each node. The node with minimum weight is more desirable to select as the cluster head. The metrics are dependent upon the objective of the clustering algorithm. In the weighted clustering algorithm (WCA), the weights are defined on the basis of four metrics: degree, mobility, transmission power and battery power. It aims to minimize the number of clusters and the control communication overhead.

In addition to the above clustering algorithms, other algorithms such as power-aware clustering, load balanced clustering and low cost of maintenance clustering have also been proposed. They aim at providing an energy-efficient, well load balanced, scalable and stable hierarchical structure with low control communication overhead [7]-[8].

Forming clusters with minimizing the number of clusters, maximizing stability and scalability of clustered topology are the most desirable objectives of the clustering algorithms. Since these problems are NP-hard problems, evolutionary algorithms (e.g., GA) and swarm intelligent based methods (e.g., ACO) have been examined for solving them in polynomial time [9]-[10]. As an example, a genetic algorithm is applied to modify the performance of weighted clustering algorithm (WCA) to minimize the dominating set and maximize the connectivity [9]. A distributed WCA that defines a local cost function [11] has also been examined for forming clustered topology. Finding a local solution for clustering and overcoming the control communication overhead are the main contributions of this distributed method. In the GA-based distributed method, the cluster heads selection process is done by only using the local information [11]. Combinations of ant colony optimization (ACO) and weighted-combined algorithm (WCA) have been suggested as efficient schemes for clustering. They aim to minimize the number of clusters, re-affiliations, and also maximize the stability and throughput. Examining the ACO-based method for the different sizes of networks proved that it has the capability to find the minimum number of cluster heads while satisfying the connectivity at a reasonable time complexity.

Another instance of ACO-based clustering schemes that was suggested in [12] defines a new metrics ‘computing power’ [12] and combines the WCA and the ACO to improve the performance of WCA. The algorithm forms the clusters to maximize the throughput and load balancing while minimizing the delay and the re-affiliations rate.

Most clustering algorithms form clustered network topology with a minimum number of clusters as the objective, which causes a reduction in control communication overhead. For such a clustered topology a lower number of channels is required. The spectrum efficiency is maximized by selecting a lower number of nodes as cluster heads while optimizing the distance and overlap between clusters. The spatial reuse clustering algorithms investigate the possibilities of forming clusters to optimize spectrum utilization. However, selecting cluster heads to minimize inter-cluster interference has not been sufficiently studied.

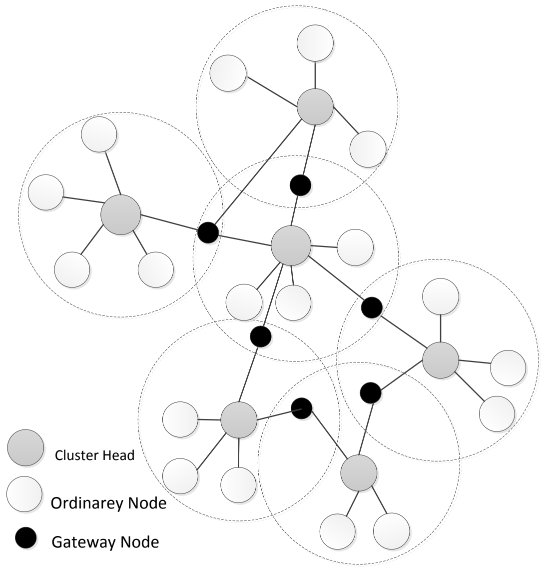


Fig.1. A clustered ad hoc network;

III. System Model and Problem Formulation

The system model of this paper is a mobile ad hoc network with a hybrid infrastructure that consists of a central access point and mobile nodes. The infrastructure of this network is similar to the previously proposed centralized ad hoc network architecture (CANA) [13]. There is a central controller that uses the cluster formation algorithm and decides to take over the role of cluster head to the nodes. The main assumptions of this model are as follows: 1) each node has an omni-directional antenna. 2) All of the nodes use similar transmission power, which will be unchanged during the cluster formation procedure. 3) The suggested algorithm is implemented for a snapshot of the network and there is no change in the network topology during algorithm execution. 4) No models for transmission activity and nodes mobility have been considered.The assumed MANET can be represented by an unidirectional graph, $G=(V,E)$, where $|V|$ is the number of nodes and E represents the communication links. There is a communication link between each two nodes which are mutually within the transmission range of each other. Using the above representation of MANET, cluster head selection is equivalent to finding a dominant set of G represented as, s [14]-[16]. The dominant set s is a subset of the graph's nodes such that $\bigcup_{v \in s} N(v) = V$, where $N(v)$ is the set of neighbors of v and is defined as equation (1).

$$N(v) = \bigcup_{v' \in V, v' \neq v} \{v' \mid dist(v, v') \leq tx_{range}\}. \quad (1)$$

A cluster head selection algorithm is equivalent to form a dominant set of G . Each node of the formed dominant set is a cluster head. As equation (2) defines, the clustering algorithm seeks an optimal dominant set, $\mathbf{x}^*$, to optimize (minimize) the defined objective function $f(\mathbf{x})$. Here, S_i is i th dominant set and n_s shows the number of dominant sets.

$$\mathbf{x}^* = \arg \min_{x \in \prod_{i=1}^{n_s} S_i} f(\mathbf{x}) \cdot \quad (2)$$

The objective function, $f(\mathbf{x})$, can be defined as equation (3), where $\mathbf{x}$ is a feasible solution, and can be represented as a vector with $|V|$ elements, where $x_p = 1$ indicates that the p th node has been selected as the cluster head, otherwise $x_p = 0$.

$$f(x) = \frac{1}{|V|} \sum_{p=1}^{|V|} x_p . \quad (3)$$

The aim is finding an optimal dominant set that satisfies the connectivity constraints. Thus, for each feasible solution, $\mathbf{x}$, a matrix Y with $n_{CH} \times n_{CH}$ can be defined. Where, n_{CH} is the number of nodes in the corresponding dominant set S or simply the number of cluster heads. This matrix is used to represent the connectivity between the nodes of the dominant set. If $y_{pq} = 1$, then the p th node and q th node of the dominant set has a connection otherwise $y_{pq} = 0$ as equation (4).

$$s.t. \frac{1}{n_{CH}} \sum_{p=1}^{n_{CH}} \sum_{q=1 p \neq q}^{n_{CH}} y_{pq} \geq 2n_{CH} \quad (4)$$

Another constraint is avoiding the potential interference between the cluster heads. Thus, for each feasible solution and its corresponding dominant set, an interference matrix, Z , with $n_{CH} \times n_{CH}$ is defined. If $z_{pq} = 1$, then the p th node and q th node of the dominant set are mutual within the interference range of each other, otherwise $z_{pq} = 0$. According to this constraint, a feasible solution should contain the IDs of the nodes that are spatially as far away as possible. This constraint can be formulated as (5).

$$s.t. \frac{1}{n_{CH}{}^2} \sum_{p=1}^{n_{CH}} \sum_{q=1}^{n_{CH}} z_{pq} = 0 \quad (5)$$

IV. ANT COLONY OPTIMIZATION (ACO)

Ant colony optimization meta-heuristic (ACO_MH) is a collection of algorithms which are inspired by the 'foraging behavior of real ants' [17]. Real ants start from the start node and use both local and global knowledge to construct the shortest path to the destination node. The ACO-based algorithms imitate this behavior to find the optimal sequence of nodes, i.e. the path with the minimum cost [17]. To solve an optimization problem using ACO-based algorithms, the problem is represented by a graph $G' = (V', E')$ to construct a sequence of nodes, a solution. In graph, G' , the nodes, V' , represent the components of the problem and the links, E' , indicate the transition between nodes. The general components of ACO-based algorithm are summarized as follows [17]-[19]:

1. A population of ants which memorize the traversed paths.
2. A graph that represents the optimization problem.
3. An initial state which is assigned to each ant and determines the starting node for that ant.
4. A 'probabilistic transition rule' [18] is used by each ant to make a decision to move to the next node. It is defined on the basis of heuristic information and pheromone intensity.
5. A Heuristic function, which is 'problem dependent function'[18], to indicate the desirability of selected node.
6. Pheromone intensity that represents the desirability of selected path. This desirability of each path is described from the perspective of other ants.
7. An updating rule for pheromone intensity is used to determine the effect of the previous deposited pheromones. In this paper, we adopt the updating rule that is defined according to 'ant colony system' [18]. Hence, the pheromone is updated by the best global ant.
8. A set of feasible nodes, N_i^k , in order to avoid forming a loop during the path construction. It

shows the feasible nodes from the perspective of ant k when it is placed on i th node.

9. A cost function is assigned to each complete path to show how profitable the path is.

A. ACO for forming Clusters

Let us assume that an ACO-based clustering algorithm is applied to form clusters for a MANET with n_{Manet_Size} mobile nodes with unique IDs. A completed path is a sequence of nodes which are selected as cluster heads and satisfies the problems' constraints (see Figure 2).

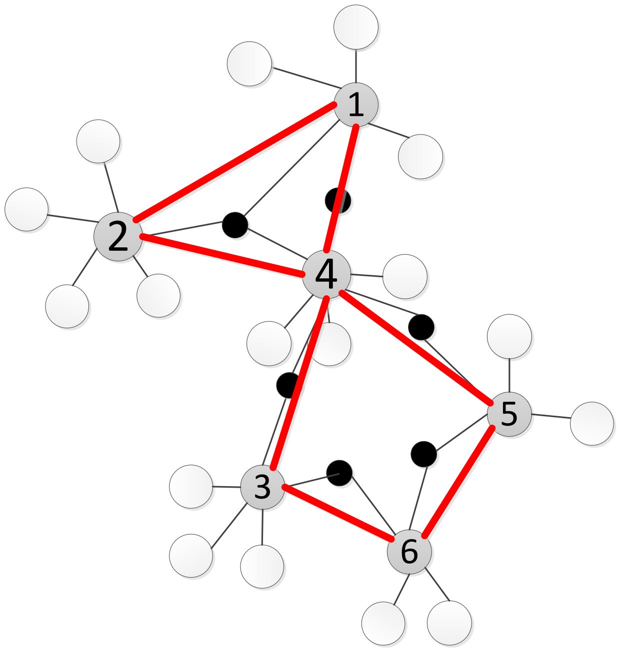


Fig.2. A red line shows an instance of completed path.

The suggested ACO-based clustering algorithm aims to form a clustered network topology minimizing the objective function that is defined as equation (2). On the other hand, the ACO-based clustering seeks a dominating set as $\mathbf{x}^*$ satisfying the constraints. The characteristics of the ACO-based clustering algorithm can be summarized as follows:

The graph of problem, $G'=(V',E')$, is constructed using the node's ID. Thus, the graph nodes, V', represent the node's ID and the links, E', represents the transition between nodes. Each ant can start from a graph node and incrementally selects one node in order to be a cluster head; it continues until it reaches to the termination condition.

1) Encoding and Initialization of Popualtion:

As was mentioned, ants are placed on different source nodes that are chosen according to the node's degree. Thus, the ants are placed on the m nodes with the highest degree. The degree of each node, d_v, is calculated as equation (6).

$$d_v = |N(v)| \tag{6}$$

The node is selected as the cluster head using their nodes' IDs. The selected nodes and their members are removed from the feasible set.

2) Cost function and power:

We define two cost functions. The first one is a single objective function as equation (7) and is defined to find a minimum dominant set. The second one is a multi-objective function as equation (8) that is defined as a combination of the optimization function of equation (7) and its constraints as equations (5) and (6).

$$f_1(x) = \frac{1}{|V|}\sum_{p=1}^{|V|} x_p \tag{7}$$

$$f_2(x) = \frac{w_1}{|V|}\sum_{p=1}^{|V|} x_p + \frac{w_2}{\sum_{p=1}^{n_{CH}}\sum_{q=1 p\neq q}^{n_{CH}} y_{pq}} + \frac{w_3}{n_{CH}^{\ 2}}\sum_{p=1}^{n_{CH}}\sum_{q=1}^{n_{CH}} z_{pq} \tag{8}$$

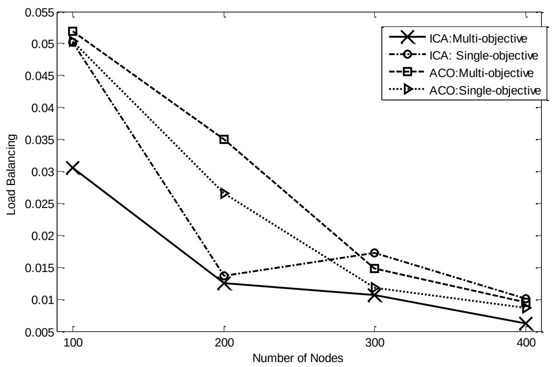
V. Simulation

We have used MATLAB to simulate different configurations of MANETs (each configuration is simulated 20 times). In order to evaluate the suggested method three factors are considered: connectivity factor, load balancing factor and potential interfering cluster heads factor. These factors can be defined as follows:

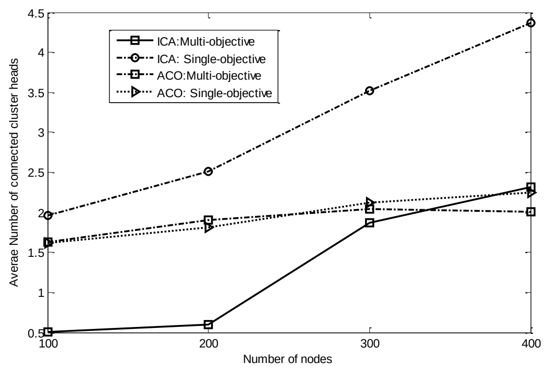
1. The connectivity factor is defined as the ratio of the number of connected cluster heads to the number of clusters.
2. The load balancing factor defines a quantity to measure how the mobile nodes are distributed among the clusters. A well balanced clustered topology has a high value for the load balancing factor.
3. The potential interfering cluster heads factor is defined as the number of clusters that have interference with each other after assigning a similar channel to all of them.

We also compare the obtained results from ACO-based algorithms with the results of another clustering procedure that is based on imperialist completive algorithm (ICA) [20]-[22]. As the first experiment, we consider networks with: 100, 200, 300 and 400 nodes. The nodes are uniformly distributed in a 1000 x 1000 meter square area. The transmission range and interference range of the nodes are fixed and set to 250 meters and 500 meters, respectively. Table I lists the obtained results from the ICA-based clustering method, the lowest-ID (LID) and ACO-based clustering algorithms that have been applied as the cluster heads selection in [12].

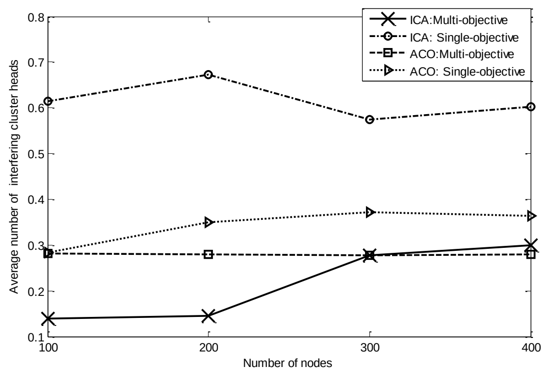
The results from a modified version of the weighted clustering algorithm presented in [12] are also mentioned in Table I. It can be observed that the clustered MANET using the ICA has a smaller number of clusters than ACO-based method and the modified WCA method. The connectivity, the load balancing and the number of potential interfering cluster heads are depicted in Fig. 3.



(a)



(b)



(c)

Fig. 3. The curves of different performance factors for ACO-based clustering algorithm; (a). load balancing factor; (b). the connectivity; (c). average number of interfering cluster heads.

As Figure 3.(a) shows, an increase in the number of nodes causes a decrease in the load balancing factor for all clustering methods. However, the ACO-based clustering algorithms have higher values for this factor than the ICA-based methods. The connectivity between the formed clusters are depicted in Figure 3.(b); it shows that the connectivity increase as the number of nodes rises. It is noticeable the connectivity factors of ACO-based method are similar for single-objective and multi-objective function. However, the obtained connectivity factor from the single-objective clustering algorithm is higher than the corresponding value of the multi-objective algorithm. Using the single-objective function to form clusters increases the number of potential interfering cluster heads, Figure 3.(c).

TABLE I. COMPARISON BETWEEN DIFFERENT CLUSTERING ALGORITHMS

Method	Characteristic			
	Algorithm Specification			
	No.of Population	***No.of Iteratio n***	***No. of Nodes***	***No. of Cluster***
ACO: Single-objective	7	50	100	12.8
	7	70	200	11.85
	12	100	300	12.45
	12	150	400	13.3
ACO: Multi-objective	7	50	100	13.10
	7	70	200	14.4
	15	100	300	15
	15	150	400	14.95
LID [17]	--	--	100	5
	--	--	200	6
	--	--	300	8
	--	--	400	9
ICA: Single-objective [20]	33	100	100	7
	67	100	200	8
	50	100	300	13
	40	100	400	15
ICA: Multi-objective[20]	33	100	100	7.3
	67	100	200	8.25
	50	100	300	14
	40	100	400	16
WCA- based ACO[12]	--	--	100	5
	--	--	200	10
	--	--	300	15
	--	--	400	20

The convergence characteristics of the ACO-based clustering algorithm using the single-objective and multi-objective function are given in Figure 4. Using the ACO-based algorithm, the multi-objective function is converging faster than the single-objective function, Figure 4 the dashed black line and the solid blue line.

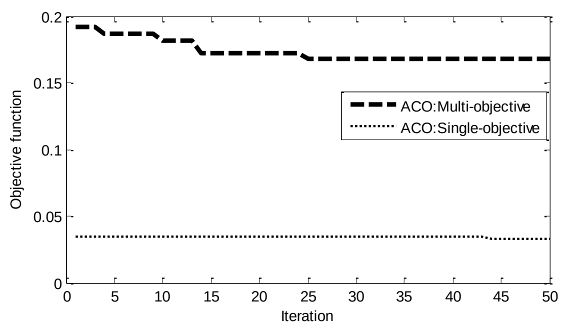


Fig.4.The convergence behavior of ACO-based methods for a MANET with 400 nodes.

VI. Conclusion

In this paper a meta-heuristic method for cluster formation for a MANET is presented. The suggested methods are examined for several scenarios and their performances are compared with other clustering methods, in particular ICA-based methods. The obtained results indicate that our suggested method finds better solutions in terms of minimizing the number of clusters and the number of potential interfering cluster heads. As future work, we will consider the distributed method on the basis of the proposed centralized algorithm.

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