An Efficient approach for Cluster Head Selection in Mobile Ad Hoc Networks (MANET)

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Abstract: Ad hoc mobile devices consist of a diverse set of independent devices that communicate over a wireless channel while moving in an unpredictable manner. These devices are typically characterized by non-deterministic mobility patterns. Clusters are formed by grouping nodes together, with cluster heads being elected to manage the network, serve as a backbone, and route packets to other cluster heads. However, many policies for selecting cluster heads tend to favor certain nodes, leading to biased elections. Due to the increased communication responsibilities, cluster heads may experience faster energy depletion, potentially causing them to drop out of the network. This paper proposes a reliable scheme for cluster head election, ensuring that all nodes have the opportunity to serve as cluster heads. The proposed approach also enhances existing algorithms to reduce the uneven distribution of nodes across cluster heads and extends the active lifespan of nodes in the network. The scheme selects the optimal cluster head and allows nodes with low power to relinquish their headship to others.

Keywords: Adhoc network, load balancing, clustering, MANET

1. INTRODUCTION

A Mobile Ad Hoc Network (MANET) is a type of network where nodes communicate via a multi-hop shared radio channel, using a shared medium without the need for fixed infrastructure, making it cost-effective and easy to set up. Nodes within this network communicate directly if within range, but they can also relay data through other nodes when out of direct reach. The dynamic and unpredictable topology of MANETs, due to the free movement of nodes, presents unique challenges, particularly in ensuring scalability and maintaining effective communication. Flat MANETs, where all nodes store the network's topology, are typically suited for smaller networks due to scalability issues. In contrast, hierarchical MANETs address these issues by organizing nodes into clusters, each managed by a cluster head, with gateways facilitating communication between clusters. Clustering in MANETs offers several advantages, including better bandwidth utilization, improved mobility management, and efficient power management [1], [2], [3], [4].

To tackle the inherent challenges of MANETs, including dynamic network behavior, link failures, and energy constraints, this paper proposes a novel clustering algorithm aimed at forming stable and scalable clusters. This algorithm improves the process of electing cluster heads, ensuring that every node has an opportunity to serve in this role, thereby balancing the energy consumption and extending the network's lifespan. The proposed approach minimizes message overhead within the cluster, maintaining the cluster structure and ensuring efficient communication. The benefits of cluster-based architectures in sensor networks are highlighted, particularly their suitability for data fusion, as data from cluster members can be aggregated at the cluster head before being transmitted to other nodes or base stations [5], [6], [27].

2. RELATED WORK

A significant amount of research has been conducted on selecting cluster heads in MANETs. For instance, in [7] and [8], the authors introduced the link cluster algorithm, where the cluster head is selected based on the node with the highest identity number among group members in the network. The maximum connectivity algorithm, proposed by the authors in [9], selects the cluster head based on the node with the maximum number of neighboring nodes and the highest throughput. However, the system performance tends to decrease as the number of nodes in the network increases. Another popular algorithm, the lowest-ID algorithm presented in [8], selects the cluster head based on the node with the lowest virtual identification number. Several modifications have been made to this algorithm to improve cluster head selection and management, making it more suitable and power-efficient, as discussed in [10], [11], and [12]. Despite these advancements, these schemes still struggle to effectively elect the most suitable node as the cluster head.

Mobility is a distinctive feature of MANETs, which leads to frequent topology changes, cluster head re-elections, and route invalidations, as highlighted in [13], [14], and [15]. In mobility-aware clustering, nodes with similar speeds are grouped together under the same cluster head to enhance stability and collaboration. The authors in [16] developed a mobility-based algorithm where each member calculates relative mobility values concerning neighboring nodes, which are then used for cluster head election. This method, however, results in significant communication overhead and latency during cluster formation. Another challenge in MANETs is the extensive power consumption by cluster heads, which are involved in every routing and broadcasting activity. If a cluster head remains in control for too long, it risks depleting its power, leading to network partitioning and communication disruption. In [17] and [18], the authors proposed energy-conserving clustering schemes, including a distributed heuristic clustering scheme for two-tiered MANETs and an energy-aware DS-Marking algorithm. Although these algorithms are effective, densely populated networks can lead to an increased workload for cluster heads. The max-min-D-cluster algorithm proposed in [19] forms a d-hop dominating set, but lacks a limit on the maximum cluster size, which can result in overloaded clusters. The Distributed Cluster Algorithm (DCA) presented in [20] introduces a weight-based scheme for cluster head selection, although the method for assigning weights to nodes was not thoroughly addressed. This algorithm partitions nodes into clusters and adapts to changes in network topology.

3. ENHANCED CLUSTER HEAD SELECTION ALGORITHM

To set-up a proficient cluster, a central or distributed (k, r) dominating set finding algorithm is used for selecting the nodes that act as coordinators of the clustering process. In the process of selecting dominating nodes, redundancy is achieved by choosing the value of the parameter k greater than one and parameter r allows increased local availability. The following are concerns that need to be addressed while designing and implementing SCAM clustering algorithm as proposed in [20]:

[1] Selection of the minimal number of cluster heads, which yields high throughput but with low latency as possible.
[2] Efficiency and stability of the created clusters.
[3] Network scalability
[4] Mechanism to prevent the clusters from growing too large. If the clusters grow too large, the load on the cluster head becomes too heavy for it to handle.
[5] Maintenance mechanism for the existing clusters. Most existing clustering algorithms create new clustering structures from scratch after a specified time interval.

We based our research on the above algorithm in setting up the cluster and incorporating the use of fuzzy logic as proposed in [24] and concept of load transfer in the determination of the cluster head. We propose an enhancement to the whole process of clustering.

The Clustering is divided into three phases:

- **i.** Election of the Cluster Head,
- **ii.** Selection of the Cluster Head, and
- **iii.** Load Transfer from one Cluster Head to another as in [25].

A. Election of the Cluster Head

The cluster head plays a major role by coordinating all activities on the network as explained earlier. The elected cluster head acts as a base station by forwarding packets and communicating with other cluster heads. It communicates with other clusters through respective cluster heads or through gateways by sending and receiving data, managing and controlling messages on the network. There have been several algorithms for cluster head selection as discussed in the related works section of this paper. The factors that influence an algorithm in cluster head selection as outlined in [22, 26] include geographical location of the node, stability, mobility of the node, energy, capacity and throughput of the node. The election of the cluster head is done using the Lower Identify (LID) algorithm.

Parameters for cluster head selection

- SOCH: set of all the cluster heads
- CHN: Cluster Head Node
- NT: Total number of nodes in the sample area
- CR: The nodes covered under a cluster head
- NR: Node Range (25 Units)
- Ni : Node under consideration
- NC: Set of respective Cluster Head that can take the current node under its own cluster

4. PERFORMANCE EVALUATION

Simulation Bed

The simulation environment for our study is characterized by several key parameters. The mobility pattern of the nodes is non-deterministic, meaning that their movements are unpredictable. Nodes move at a rate not exceeding the range of one node per unit time within a 200 x 200 square unit area. The exact size of each cluster is not predefined, adding to the complexity of the simulation. The total number of nodes varies, with simulations conducted for 25, 50, 75, and 100 nodes. The sample time for monitoring node activities is set at 100 milliseconds. Each node has a fixed communication range of 25 units. The total work budget available for the simulation is 5000 units, and nodes perform random work with a maximum work output of 10 units deducted from this budget. This setup is designed to emulate a dynamic and resource-constrained environment, providing a robust test bench for evaluating the performance of clustering algorithms in MANETs. The NS2 software simulator tool is used to test the performance against other existing protocols. The simulated ad hoc network is composed of slowly changing network topology. The topology has a square area with length 200 and width 200. The network nodes are randomly distributed.

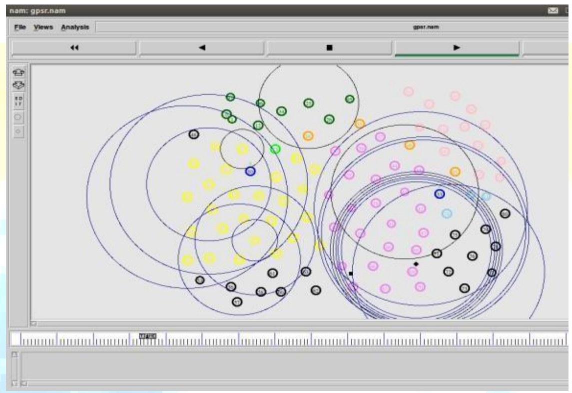

Fig 1. Clustering formation

Initial energy (Work Budget) of all the nodes in the network is 5000. The range of each node is 25 units which is taken as input to the program. The movement speed of a node can vary between 0 and 1 as shown in figure 1. The mobile nodes move according to the “random waypoint" model. Each mobile node begins the simulation by remaining stationary for pause time seconds. It then selects a random destination in the defined topology area and moves to that destination at a random speed. The random speed is distributed uniformly between zero and maximum speed of not more than 1 the communication range of a node. Upon reaching the destination, the mobile node pauses again for pause time seconds, selects another destination, and proceeds as previously described. This movement pattern is repeated for the duration of the simulation. One of the major parameters where we can easily asses the quality of the algorithm is the average cluster head time. This gives us a fair idea of the network lifetime. Hence, we compare our proposed algorithm with the existing algorithm.

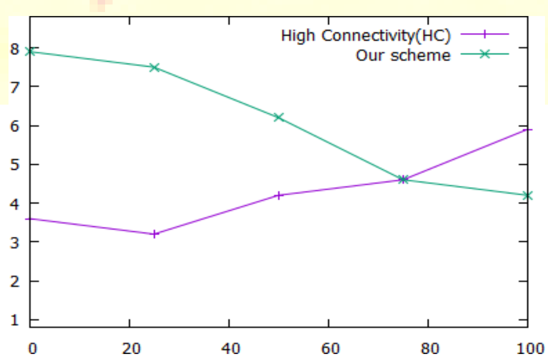

Fig. 2 High connectivity vs our scheme

The network shows low network lifetime in HC initially because the number of nodes are less. Less nodes amount to lower network lifetime. With the enhancement incorporated we see that the initial network lifetime i.e. with less number of nodes has improved because there was a better distribution of nodes under each cluster head.

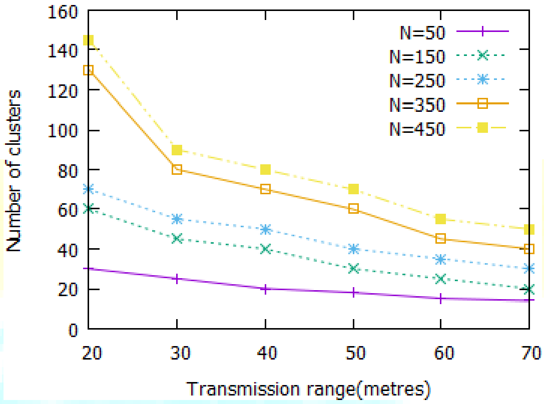

Fig. 3 Transmission range against number of clusters

Fig. 3 shows that the average number of clusters is relatively high when the transmission range is small. The results shown are for varying values of total number of nodes. When the transmission range increases, more and more nodes are connected to the same cluster head resulting in reduced number of clusters created. A smaller backbone is desirable for minimizing the routing overhead. Hence, transmission power of a node is also a deciding factor for finding the quality of dominating nodes. When the transmission range is increased from 20 to 40 m, the number of clusters created is reduced considerably. But the rate of reduction in the number of clusters created gets reduced on further increase in the transmission range. The power consumption is high for higher transmission range. Hence, the recommended value of transmission range is between 30 and 40 m.

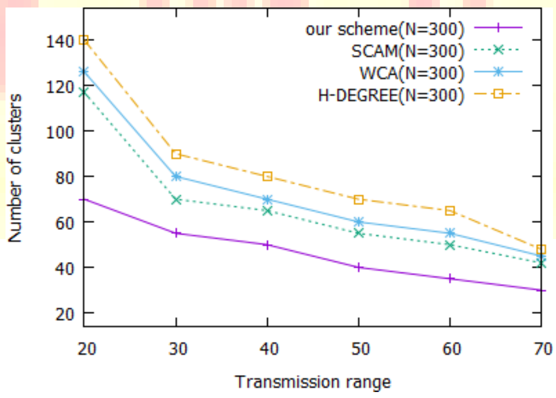

Fig. 4 Analysis of No of clusters in proposed scheme, SCAM WCA, and H-degree

Fig. 4 compares the number of clusters formed for Our scheme, SCAM, WCA and H-degree as a function of the transmission range. The results show that the average number of cluster heads selected using our scheme is less compared with SCAM, WCA, and H-degree. This is because they create less number of clusters when the cluster radius increases and make use of the cluster merging process. But increased radius leads to increased cluster size, which adversely affects the performance. So the selection of radius is critical over here.

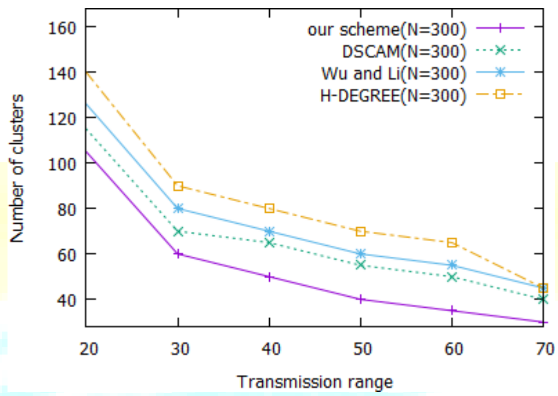

Fig. 5 Comparison of number of clusters in our scheme, DSCAM, Wu and Li , and H-degree

Fig. 5 shows the number of clusters formed for our scheme, DSCAM, Wu and Li, and H-degree as a function of the transmission range. Our scheme creates less number of clusters compared with the other protocols. This is because our scheme forms less number of clusters with larger values of radius and uses pruning techniques to reduce the number of cluster heads number of nodes in the sample area increases, the network lifetime decreases because, all the cluster heads have to handle greater responsibilities. But this fall in the network lifetime is stabilized as the nodes increase.

5. CONCLUSION

In conclusion, this study presents a novel clustering algorithm for Mobile Ad Hoc Networks (MANETs) that enhances cluster head selection and management. The proposed algorithm addresses key issues such as biased cluster head elections, uneven distribution of nodes, and rapid energy depletion among cluster heads. By ensuring that all nodes have an opportunity to serve as cluster heads and incorporating load balancing techniques, the algorithm improves network efficiency and extends node lifespan. The simulation results demonstrate that the proposed approach outperforms existing clustering schemes by reducing the number of clusters while maintaining stability and minimizing communication overhead. This advancement contributes to better scalability and more efficient power management in MANETs, ultimately enhancing the overall network performance and longevity.

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