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A Stable and Energy Efficient Clustering Algorithm for Mobile AD HOC Networks

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Abstract: Wireless ad hoc network is a network of portable devices that can be able to function without any infrastructure. It is having the self-organizing capability without any centralized coordinator. Clustering is a process of hierarchically organizing nodes. Clustering consists of a set of mobile nodes that work together and so it can be viewed as a single system. Since the volatile nature of the mobile nodes, their associations to and from the clusters affects the stability of the cluster. This unstable nature of nodes results in higher rate of re-clustering and re-affiliations. To enhance the stability of the network, in this paper, we introduce a stable and energy efficient clustering algorithm (SECA). We have formulated a novel method that effectively balances all the parameters like node mobility, energy and degree of the node. The simulation results clearly indicate that the proposed clustering scheme considerably reduce the average number of re-affiliations, reclustering and increase the stability of the cluster.

Key words: Clustering · Energy-efficient · Geometric mean · MANET · Stability

INTRODUCTION

Mobile ad hoc network is a type of self-organized and vibrant natured multi-hop wireless network consists of mobile nodes that are capable of communicating with each other even when there is no preset infrastructure. It is a random organizable network where nodes have mobile nature with dynamic topology [1]. Ad hoc networks are used especially in armed forces, crisis situations, disaster rescue operations and sensor networks. Since the mobile nature of nodes, ad hoc network naturally has a dynamic topology. Also, the nodes are operated using battery power and it confines the resources such as memory and bandwidth. Another issue of ad hoc networks is the scalability problem. Mobile Ad-hoc Networks suffer from the problem of mobility, scalability and energy depletion. This kind of distinctive features motivates the design of new mobile ad hoc networking protocols.

In MANET there are two types of routing can be used either flat routing or hierarchical routing [2]. In flat routing, the nodes forward the information needed to any router that is able to reach or receive information. In hierarchical routing often the nodes are organized into a hierarchy. This type of hierarchical routing is known as clustering.

In flat routing, the overhead with the control packets is too much and it has very poor scalability. In the hierarchical routing, control overhead, routing overhead considerably decreases when comparing to flat routing. Cluster based routing maintains smaller size routing tables comparing to the flat routing scheme. Failures can be cut off in hierarchical routing so as to minimize the cost of route maintenance.

Though clustering has many advantages, the unique characteristics and constraints of the ad hoc network are making the clustering process an exigent task.

The cluster structure of a typical dynamic ad hoc network, a special mobile node, called "clusterhead", facilitates the coordination of the system. A typical cluster structure has been shown in Figure 1.

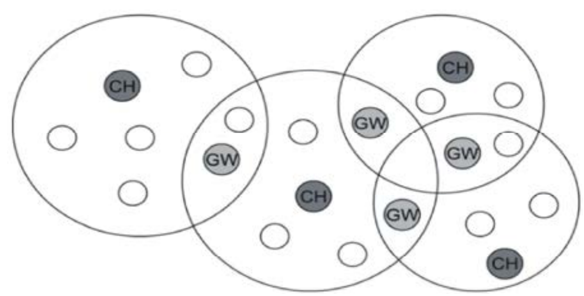

Fig. 1: Cluster example

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In a cluster, if any two nodes lie within their range of transmission are said to be neighbors and when both of them lie and set up a bidirectional link between them. The nodes in clustering play one of the following role given below:

- Clusterhead (CH): CH acts as the local controller for the cluster. The clusterhead's responsibilities are routing, scheduling of intra-cluster traffic and channel allocation for cluster members.
- Cluster Member: A normal mobile node belonging to a cluster. Cluster members habitually do not participate in routing, particularly in the cluster to cluster communication.
- Gateway Node (CG): Cluster gateway lies at the border which is used to convey the routing information from one cluster to another. An example set-up of clustered network along with these nodes is shown in Figure 1.

The selection of clusterhead node plays a major role in forming the clusters. There are so many methods have been proposed in the past. A good number of them are discussed in the literature review described in section II. This research work focuses on selecting a clusterhead which is a stable one and also form the clusters in such a way that they have minimum overhead. That is, the clusters will have a minimum reaffiliation rate and reclustering rate.

Literature Review: The selection of the clusterhead can be based on either a single metric such as node degree, node id, energy or multiple metrics, i.e combination of more than one metric considered by assigning appropriate weights to each metric [14]. The node which wins the weight compared with its 1-hop neighbors is chosen as clusterhead.

Lowest ID algorithm [3, 4] is the most simple clustering algorithm that basically selects clusterhead on the basis of the unique ID assigned to a node. But this method has numerous drawbacks. No upper limit for the number of nodes is defined in a cluster. This leads to overloading of clusterhead nodes. Also, no network related parameters are taken into consideration so the performance of such network is unpredictable. Highest Degree Algorithm [5] is just considering connectivity alone. Clusterhead selection takes place on the basis of the degree of each node. In this method, there is no maximum limit on the number of nodes per clusterhead so clusterheads may become overloaded. Also, this scheme does not provide any quantitative measure of stability.

In MOBIC [6], mobility is considered as the primary criteria for clustering. To compute the clusterhead, Aggregate Local Mobility(ALM) is used as mobility metric. In MOBIC, mobility is considered as the evaluation criteria for stability of clusterhead. In fact, there are other factors that also need to be taken into account because single parameter will not give desired stability in all scenarios.

DMAC, proposed in [7], provides a general solution for the clustering framework. Each node is assigned a weight, based on their mobility-related parameter. DMAC [7] provides a generalized framework but still the weight metric method is not clearly specified. WCA [8], (weighted Clustering Algorithm), is also a weight based distributed clustering algorithm like DMAC. But here, weight is specifically defined. In WCA, the clusterheads are selected on the basis of combined metrics by including various parameters like its neighbor nodes, the speed of the nodes, its transmission power and battery power. In [9], the authors introduced a method, Enhancement on Weighted Clustering Algorithm [EWCA] to get better the load balancing and the constancy in the MANET.

Proposed Scheme: In this paper, a new method has been proposed to compute the weight by considering the key factors: the number of neighbors (degree) that a clusterhead can serve, moving speed of each node (mobility), energy consumption level and the energy depletion rate. A new computation formula also has been proposed. Here, the geometric mean based computation is followed rather than the arithmetic mean to better handle the above mentioned key factors. There are two parts in the proposed scheme: Selection of clusterheads and creation of clusters.

Clusterhead Selection: The process of clusterhead selection follows the below mentioned steps:

Step 1: Finding the neighbors (degree) of each node D_i

Node Degree: It refers the number of neighboring nodes(D_i) of node i. To avoid overloading in clusterhead, we fix each clusterhead to support a certain number of nodes only. For this, a threshold value $_T$ is fixed. The degree difference is computed for node i.

$\delta = |D_i - T|$, where T is a threshold

Step 2: For each node compute its Mobility (M_t)

Higher mobility of the nodes influences the lifetime of the clusters. This factor should be kept at a minimum level to choose a stable clusterhead. The symmetric difference of the proximity nodes between two adjacent beacon periods will clearly indicate the mobility of the node [10] and the mobility of a node at time t, M_t is given by;

$$M_t = \sqrt{1 - \frac{|N_i(t) \oplus N_i(t-1)|}{|N_i(t) \cup N_i(t-1)|}} \quad (1)$$

where Ni(t) and Ni(t-1) refers the number of adjacent nodes at time 't' and 't-1' respectively. The notation $A \oplus B$ denotes symmetric difference of the set A and B. |A| is the cardinality of A.

Step 3: Estimate the energy consumption level of each node.

Assuming that all the nodes are having E_{max} as initial energy and the energy exhausted is calculated by $E_{ex} = E_{max} - E_{res}$ where E_{res} is the residual energy of the node at given a point of time. This factor is also expected to be taken as a minimum since the node whose energy is exhausted more will end its life sooner.

Step 4: Calculate the energy depletion rate

Depletion rate is an important metric that measures the energy decreasing rate in a given node. Each node observes its energy utilization because of various processes like the transmission, reception and overhearing activities. Energy depletion rate [11] (EDR) at time t is computed by

$$EDR_t = \propto * EDR_{old} + (1-\propto) * EDR_{sample} \quad (2)$$

where EDR_{old} is computed by a proven exponential weighted moving method during the previous interval. EDR_{sample} is the newly observed energy depletion rate.

We have used geometric mean to compute the metric of each node which is given in the formula given below. We prefer geometric mean because it does not allow one factor is dominated by other factors. Geometric mean gives a better optimized value than the weighted arithmetic mean, especially when handling multiple parameters [12].

$$Metric_t = \sqrt[4]{(\delta * M_t * E_{ex} * EDR_t)} \quad (3)$$

Table 1: Simulation parameters

Parameters	Meaning	Value
N	Number of nodes	25, 50, 75 nodes
X x Y	Size of the network	100 m x 100 m
Speed	Speed of nodes	5 to 35 m/s
Transmission Range	Transmission radius of each node	10 to 70 m
T_x	Transmission Power	5 W
R_x	Receiving Power	3W
E_{max}	Initial energy	100 J
PT	Pause time	0 seconds
HI	Hello Interval	3 seconds
Duration	Time of simulation	600seconds

Cluster Formation: Cluster maintenance is the second phase of the clustering process [13]. The formation of a cluster involves logical partition of the mobile nodes into several clusters and selection of clusterheads for each group. Initially, each node broadcast hello message to all the nodes in its transmission range. Hello messages consist of node identification, their position, the role of each node and metric value of the node at time t which is calculated by equation 3. The node which has the least metric value will announce itself as clusterhead to all its neighbors. The corresponding nodes will join that clusterhead and thus a cluster is formed.

Simulation Environment and Parameters: We have used ns-2.34 [15] for doing our simulation. The simulation area considered is 200 x 200 meters with the transmission range varying from 10 to 50 meters.

The transmission range for all the mobile nodes in the network is kept same for each experimental setup. The scenarios are created using setdest utility in NS-2. Each node is located in random position and each node is moving with the maximum speed of 5 m/s in a random direction between $(0, 2\pi)$. Nodes moved randomly at each time unit and the random waypoint mobility pattern is used here. Each simulation has been run up to 600 seconds and the final result is the average of 20 runs. The simulation parameters are shown in the Table 1.

RESULTS AND DISCUSSION

Performance Metrics: We are interested in the following metrics to evaluate the performance of our proposed work:

- Reaffiliation rate: Defined as the numbers of times the member node relieves from one cluster and joins in another cluster in one second. Lower this value implies better cluster stability.

- Reclustering rate: defined as the number of times the clusterhead changes occurred in one second during the entire simulation. A lower reclustering rate implies better cluster stability.
- Cluster lifetime:defined as the average time duration a CH retains its role. The maximum value of cluster lifetime is desirable to reduce path breaks during routing.
- Average residual energy: denotes the average value of all the clusterheads' remaining energy. The maximum value of this metric will be favorable for prolonging network lifetime.

During simulation, we have analyzed the above said clustering metrics by considering transmission range (varying 10-70 m) and by varying speed of nodes. These simulations have experimented for the size of 25, 50 and 75nodes in the network. Each plot in the graph is the computation of the average of 25 simulation runs of different scenarios. The same scenarios have been taken for WCA to compare with the proposed work SECA.

Reaffiliation rate in WCA and SECA has been compared in Figure 2 and 3. These graphs indicate that SECA gives better results than that of WCA. The Figures 4 and 5 show the analysis of reclustering rates in WCA and SECA by varying transmission range and the speed of the nodes. SECA gives 16% better performance than WCA. Also, SECA provides 13% longer cluster lifetime which is shown in Figure 6.

During the simulation, we have analyzed the average residual energy of clusterhead nodes in both SECA and WCA. The proposed method, SECA, shows 11% energy efficiency than WCA which is depicted in Figure 7.

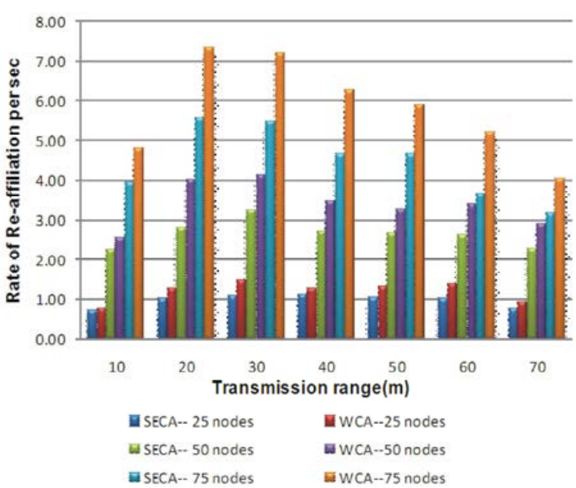

Fig. 2: Comparison of re-affiliation rate while changing transmission range

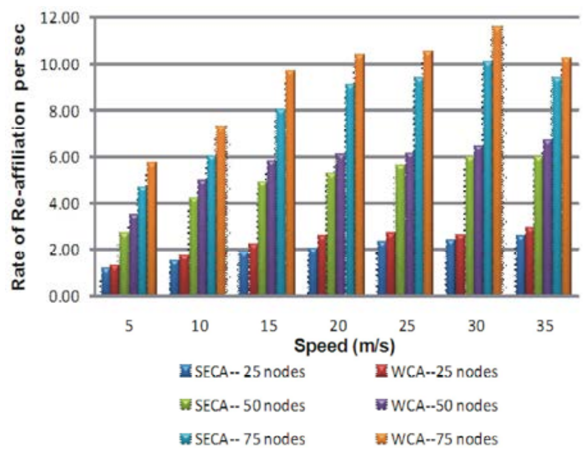

Fig. 3: Comparison of re-affiliation rate while changing speed

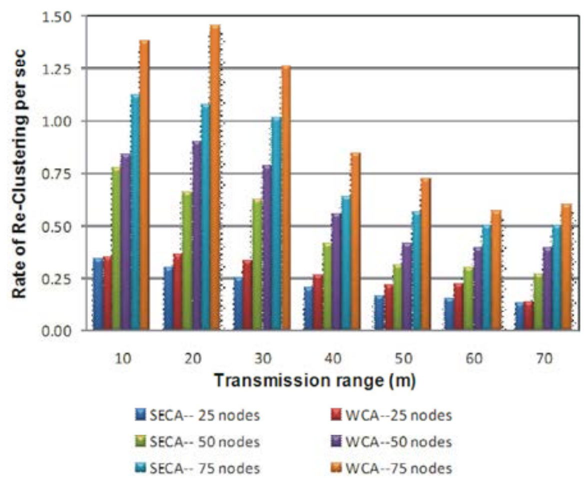

Fig. 4: Comparison of re-clustering rate while changing transmission range

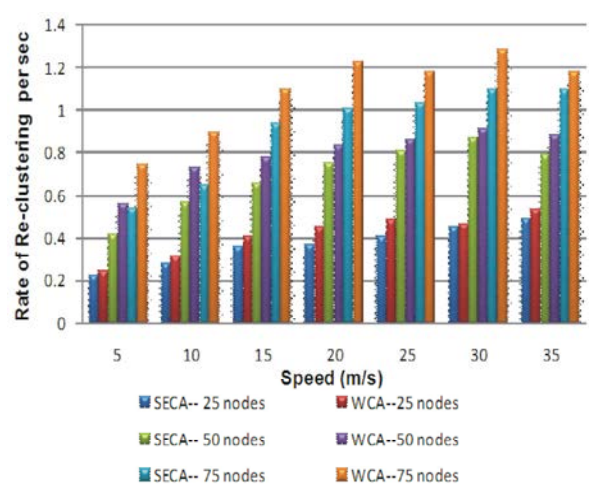

Fig. 5: Comparison of re-clustering rate while changing speed

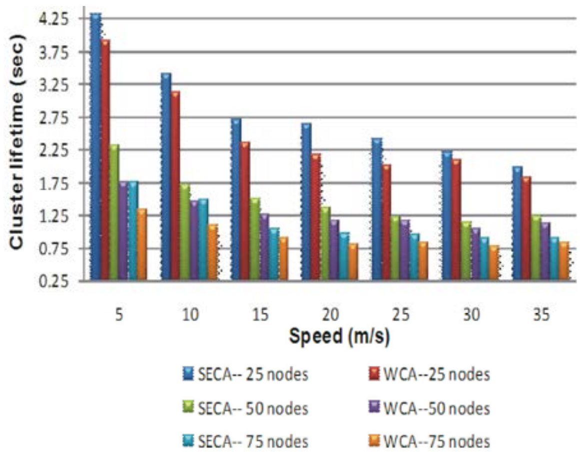

Fig. 6: Comparison of cluster lifetime

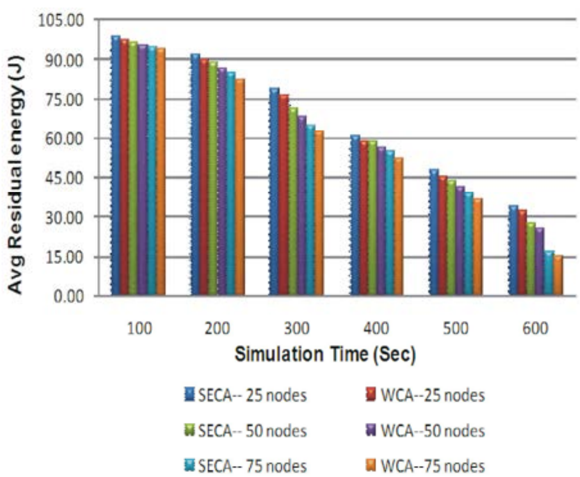

Fig. 7: Comparing residual energy of clusterhead nodes

CONCLUSION

In our experiment, we have considered four key parameters node degree, mobility, energy exhausted and energy depletion rate to select the clusterhead. Also, our weight computation formula uses the geometric mean which guarantees optimum result than the weighted arithmetic mean. The simulation results clearly prove that SECA has better stability and energy efficiency than its prior works. Especially, it outperforms WCA in all key aspects. This work can be further optimized by using any of the nature-inspired optimization techniques.

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