Toward Stable Clustering in Mobile Ad Hoc Networks

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***Abstract*—This paper proposes a novel clustering scheme that aims to address the following concerns: effectiveness and low maintenance. By constructing a multi-hop clustering backbone with small number of cluster-heads, we successfully reduce the overhead of inter-cluster maintenance and backbone changes. Next, we utilize the cluster stretching mechanism which decreases the leaving frequency of cluster-members. As the number of leaving events is reduced, the cluster topology is more stable for high-layer applications. Finally, an extensive performance evaluation verifies our results under different system settings.**

***Index Terms*—Ad hoc Networks, Multi-hop Clustering, Stability, Stretching Clustering, k-hop Dominating Set.**

I. Introduction

In MANET, the flat structure is only efficient for small and simple networks. When networks become larger, it is necessary to divide the networks into many dynamic regions [1]. For these reasons, many clustering schemes have been proposed to create a stable cluster framework and allow local management of each region [2]. There are some advantages of clustering. First, with the help of the virtual backbone, the cluster-based routing protocol in MANET can keep up with network expansion. Other applications, such as multicasting, location service [7], address assignment, and so on, are also afforded that benefit by exploiting the virtual structure. Second, local changes in one cluster require updates only in that cluster. This significantly reduces the processing and communication overhead. Furthermore, clustering allows spatial reuse of resources. For example, channel access schemes, such as TDMA, have been applied to coordinate transmissions of mobile nodes within the same cluster to enhance the system throughput [3]. These advantages explain why clustering is a hot topic of mobile ad hoc networks.

There are two categories of clustering: one-hop and multi-hop clustering schemes [1]. Until now, most research has focused on one-hop clustering, in which members are one hop away from their cluster-heads. Such schemes allow simple local management within each cluster. However, with increased network size and a greater number of mobile nodes, one-hop clustering creates many small clusters because of the small coverage area of each. These clusters are likely to be broken when mobile nodes move out of their cluster's coverage. In contrast, multi-hop clustering allows better coverage at the expense of cluster management. k-hop value is a multi-hop clustering parameter which defines the maximum distance between cluster-head and their members. So, compared with one-hop clustering, multi-hop clustering is more scalable for large networks.

Clustering in mobile ad hoc networks may address many objectives, such as effectiveness, low maintenance, mobility awareness, and load balancing, and others. The goal of effectiveness is achieved by grouping all nodes in the networks with a small number of cluster-heads. This leads to a simple and stable cluster backbone, which facilitates control in higher protocols. Schemes of this type include k-CONID, k-lowestID [4] and MaxMin [5]. Low maintenance clustering schemes focus on reducing the frequency of maintenance events, such as reclustering, merging, splitting, leaving, and joining. There are also many studies about topology control which improves communication reliability by adjusting the transmission range of mobile nodes.

In [5], it is shown that the minimum k-hop dominating problem is NP-complete. Moreover, the paper proposes a heuristic algorithm, MaxMin, to form k-hop clusters by diffusing the node ID along wireless links. Each node participates in 2 phases each of which is limited to k rounds of message exchange. The number of messages is a multiple of k, which leads to small construction overhead. Like MaxMin, kHOPCA [6] is a recent multi-hop clustering scheme which relies only on one-hop neighbor information. kHOPCA consists of a set of simple and easy-to-implement rules which can construct a cluster backbone by localized information.

Compared with one-hop clustering, above schemes can form a cluster backbone with smaller number of cluster-heads. However, the cluster-head ratio is still high. As cluster-heads need to exchange information and maintain the backbone,this can lead to high overhead of inter-cluster maintenance. Moreover, these schemes do not consider about leaving rate in maintenance phase.

To address these concerns, a non-overlapping, multi-hop clustering scheme is presented in this paper. Our connectivity-based stretchable clustering scheme, CSC, aims to achieve the following goals: effectiveness and low maintenance. The rest of this paper is organized as follows. In the next section, we

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discuss related works of clustering. Our proposed scheme is presented in section 3. In section 4, the performance results are shown. Finally, in section 5, we conclude the paper.

II. Proposed Scheme

Our cluster formation starts with some initiators. First, every node in MANET broadcasts hello message to its neighbors. After this broadcasting, each node knows its own node degree and all its neighbors IDs. Then, the node i that has the smallest ID relative to its neighbors sets a timer, $t_{i,1}$, and becomes an initiator. Let bcd be the small broadcasting delay, C_i be the connection degree of the node i, θ_c be the threshold of connection degree and α_c be the time factor of connection degree. Then, $t_{i,1}$ is calculated as follows:

$$t_{i,1} = \alpha_c max(0, 1 - \frac{C_i}{\theta_c}) + bcd$$

When the time expires, the initiator becomes a cluster-head and floods a cluster propagation message to every node that is at most $(2k+1)$ hops away. This message serves two purposes. First, nodes that are up to k hops away from the cluster-head become members. Second, the propagation message triggers nodes that are from $(k+1)$ hops to $(2k+1)$ hops away from the cluster-head to become cluster-head candidates. Once again, these candidates set timers. Let β_i be the distance between the current node i and the previous cluster-head ($k+1 \leq \beta_i \leq 2k+1$), α_d be the time factor of the distance. The timer $t_{i,2}$ of node i is set as:

$$t_{i,2} = \alpha_c max(0, 1 - \frac{C_i}{\theta_c}) + \alpha_d(1 - \frac{\beta_i}{2k+1}) + bcd$$

At this point, nodes which timer has expired become new cluster-heads and continue the cluster formation process by broadcasting the propagation messages. For the duration of time before the timer expires, if the cluster-head candidate receives any propagation messages, it stops waiting and becomes a member of the corresponding cluster immediately. Notice that two above equations prioritize nodes with high connection degree and far away from other cluster-heads in cluster formation.

As a node moves around, it eventually leaves its current cluster's coverage and joins another cluster. Cluster membership, routing table, and other high-level information are in need of updating, and the maintenance cost increases consequently. To cope with this issue, we apply a mechanism that uses two values for the distance between cluster-members and their cluster-heads. First, in formation step, clusters in which members are at most k hops away from the cluster-head are formed. When new clusters are formed in the splitting event, this k-hop value is also used. However, in cluster maintenance, the maximum distance is allowed to stretch to k'-hops ($k' \geq k$). In this way, as long as nodes can communicate well within their clusters, they have more freedom of movement and do not need to join other clusters. In Figure 1(a), a 2-hop cluster in which nodes A and B are 2 hops away from the the cluster-head is formed initially. In cluster maintenance phase, because of the mobility, nodes A and B cannot communicate with their cluster-head in 2 hops any more. Other clustering schemes force these nodes to join other clusters or form new ones. However, as both A and B are still well-connected to other members in the same cluster, these nodes should stay in the current cluster. In our scheme, nodes A and B stay in their cluster as long as the distances between them and their cluster-head do not exceed k' hops. By utilizing the stretching distance, nodes have more freedom of movement and do not need to join other clusters.

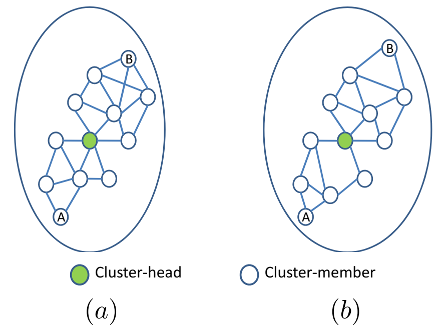

Fig. 1. Cluster stretching. $k = 2$. $k' = 3$. (a) Right after cluster formation; (b) In cluster maintenance.

III. Performance Evaluation

In this part, we simulate, study the performance result of our proposed scheme and compared our result with k-lowestID, k-CONID, kHOPCA, and MaxMin. The simulation time for each test is 5 minutes and the result is obtained by 500 running times. The number of nodes, n is from 50 to 1000; The node density, d, ranges from 8 to 12 neighbor per node; The transmission range is $250m$; Mobility model is Random Waypoint with velocity from $0m/s$ to $10m/s$; Nodes are distributed by random model in squared network area. We run the simulation with three instances of our proposed scheme with different k' value ($k' = k + \epsilon$).

We present the percentage of cluster-heads as the solution to minimum k-hop dominating set problem in Figure 2. The lower the number of cluster-heads, the simpler the backbone and the larger the cluster size. By maximizing the distance between two adjacent cluster-heads and prioritizing the connection degree, our proposed scheme achieves the smallest number of cluster-heads compared with others.

Second, we measure the number of formed or broken cluster links in backbone per minute in Figure 3. Cluster link is the logical link connecting between two adjacent cluster-heads. When one cluster link is formed or broken, the event is propagated to every cluster-head of the networks and consumes overhead. Furthermore, higher-layer cluster-based protocols such as routing, location service, etc. are affected by this change and may need to trigger update. So, reducing this metric not only affects the clustering scheme itself but also benefits other cluster-based protocols.

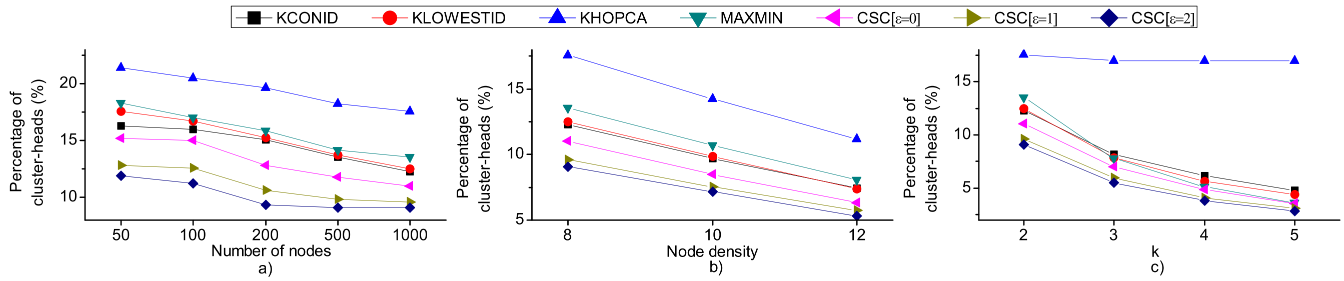

Fig. 2. The percentage of Cluster-heads: a) $d = 8; k = 2$ b) $n = 1000; k = 2$ c) $n = 1000; d = 8$.

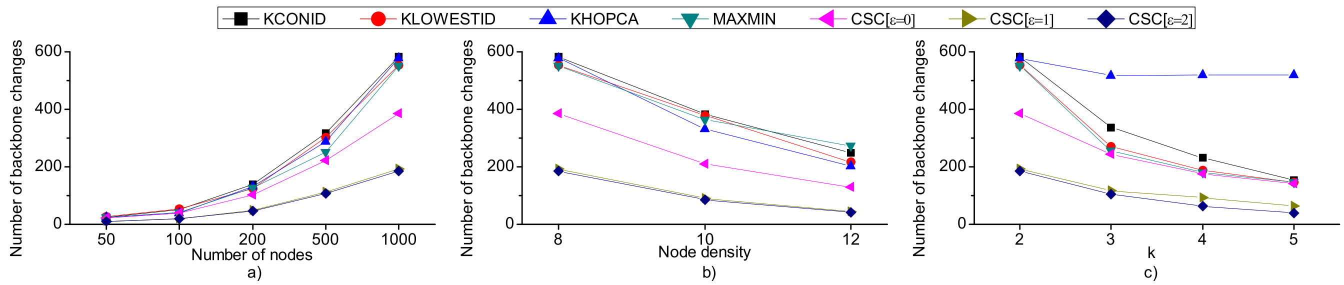

Fig. 3. The total number of formed or broken cluster links in backbone per minute: a) $d = 8; k = 2$ b) $n = 1000; k = 2$ c) $n = 1000; d = 8$.

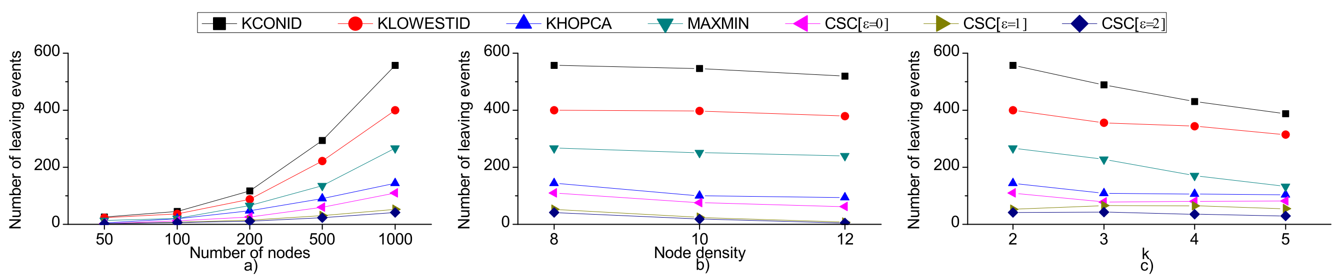

Fig. 4. The total number of leaving events per minute: a) $d = 8; k = 2$ b) $n = 1000; k = 2$ c) $n = 1000; d = 8$.

Finally, we show the total number of leaving events for mobile nodes in one minute of our scheme is smaller, as in Figure 4. By using a stretching distance k', a node can stay longer at its current cluster and the leaving frequency is reduced. Like the number of changed cluster-links, the high number of leaving events also affects higher-layer cluster-based protocols and causes update overhead in these protocols.

IV. Conclusions

Motivated by the benefits and challenges of clustering in mobile ad hoc networks, this paper presents a new clustering scheme which considers various factors. First, as the solution of minimim k-hop dominating set, our proposed scheme generates small number of clusters to reduce the backbone changes and inter-cluster maintenance overhead. Then, we utilize the cluster stretching mechanism to reduce the leaving rate which affect higher cluster-based protocols. Finally, performance result is carefully studied by comprehensive simulation in wide-scale networks.

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