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# A New Scheme for on-Demand Group Mobility Clustering in Mobile Ad hoc Networks

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*Abstract* — **Clustering is an important concept for mobile ad hoc networks (MANETs), because clustering makes it possible to guarantee basic levels of system performance, such as throughput, delay and also security issues such as availability, in the presence of both mobility and large number mobile terminals. Many clustering protocols for mobile ad hoc networks (MANETs) have been proposed in the literature. To reduce the signaling traffic load, reactive clustering may be employed. A large variety of approaches for ad hoc clustering have been presented. we have developed a clustering protocol named "On-Demand Group Mobility-Based Clustering with ability definition guest node" (ODGM/GN), which is reactive. The design process especially addresses the notion of group mobility in a MANET. As a result, ODGM/GN maps varying physical node groups onto logical clusters. In this paper, we have defined a GUEST NODE and a cluster level, and then the performance of the algorithm in the presence of nodes mobility is evaluated. The simulation results shows 5% error level for the proposed approach.**

*Keywords* — **MANET, clustering, group mobility**

## 1. Introduction

Mobile Ad hoc Network (MANET) emerged from studies on extending traditional Internet services to the wireless mobile environment which is aligned with expectations of the Next Generation Network (NGN). Due to the price of usage, WLAN is preferred in comparison with 3G. Besides WLAN infrastructure access, wireless mobile ad hoc network can be preferred as an infrastructure-less access to the Internet or broader NGN network; of course in the presence of global connectivity feature to the internet or NGN. The mentioned global connectivity comprises internet gateway functionality and a globally routable address. According to literature, utilizing a mobile gateway interconnected with common WLAN makes MANET useable as Internet or NGN access network.

The more efficient MANET, the more usable access to the Internet and NGN. Hence, in this paper a new mobility clustering scheme is introduced which increases total efficiency of the MANET. In addition, such a clustering scheme is an appropriate basis for implementing decentralized certification authority as a promotion in the total quality of security in MANET. Because of inherent properties of MANET, such as the high dynamics of its topology (due to mobility and joining/leaving devices), limited resources of end systems, or bandwidth-restricted and possibly asymmetrical communication links, it is not possible to implement a centralized architecture for securing communication in such a network.

Clustering protocols in the MANET are classified based on their objectives. According to this criterion, clustering schemes for MANET can be grouped into six categories, as shown in Table 1. Dominating-Set-based (DS-based) clustering [1-4] tries to find a DS for a MANET so that the number of mobile nodes that participate in route search or routing table maintenance can be reduced. This is because only mobile nodes in the DS are required to do so. Low-maintenance clustering schemes [5-8] aim at providing stable cluster architecture for upper-layer protocols with little cluster maintenance cost .By limiting re-clustering situations or minimizing explicit control messages for clustering, the cluster structure can be maintained well without excessive consumption of network resources for cluster maintenance. Mobility-aware clustering [9-11] takes the mobility behavior of mobile nodes into consideration. This is because the mobile nodes' movement is the main cause of changes to the network topology .By grouping mobile nodes with similar speed into the same cluster, the intra cluster links can be greatly tightened and the cluster structure can be or respondingly stabilized in the face of moving mobile nodes. Energy-efficient clustering [12–13] manages to use the battery energy of mobile nodes more wisely in a MANET. By eliminating unnecessary energy consumption of mobile nodes or by balancing energy consumption among different mobile nodes, the network lifetime can be remarkably prolonged. Load-balancing clustering schemes [12-14] attempt to limit the number of mobile nodes in each cluster to a specified range so that clusters are of similar size. Thus, the network loads can be more evenly distributed in each cluster. Combined-metrics-based clustering [15] usually consider multiple metrics, such as node degree, cluster size, mobility speed, and battery energy, in cluster configuration, especially in cluster head (CH) decisions. With the consideration of more parameters, CHs can be more properly chosen without giving bias to mobile nodes with specific attributes. Also, the weighting factor for each parameter can be adaptively adjusted in response to different application scenarios.

Based on the neighborhood graph introduced by the NRP[19], We have developed a clustering protocol named "On- Demand Group Mobility-Based Clustering with Ability Definition guest node" (ODGM/GN). As a result, ODGM/GN maps varying physical node groups onto logical clusters. The rest of the paper is organized as follows. Section two discusses, the Group Mobility Clustering in the MANET is discussed. The proposed approach is introduced in the third section. In the fourth section, the evaluation results are presented. Finally, the conclusion will be discussed.

**Table 1. Summary of Six Clustering Schemes**

| | *Objective* |
|---|---|
| DS-based clustering | Finding a (weakly) connected dominating set to reduce the number of nodes participating in route search or routing table maintenance. |
| Low-maintenance clustering | Providing a cluster infrastructure for upper layer applications with minimized clustering-related maintenance cost. |
| Mobility-aware clustering | Utilizing mobile nodes' mobility behavior for cluster construction and maintenance and assigning mobile nodes with low relative speed to the same cluster to tighten the connection in such a cluster. |
| Energy-efficient clustering | Avoiding unnecessary energy consumption or balancing energy consumption for mobile nodes in order to prolong the lifetime of mobile terminals and a network. |
| Load-balancing clustering | Distributing the workload of a network more evenly into clusters by limiting the number of mobile nodes in each cluster in a defined range. |
| Combined-metrics-based clustering | Considering multiple metrics in cluster configuration, including node degree, ability, battery energy, cluster size, etc., and adjusting their weighting factors for different application scenarios. |

## 2. Group Mobility Clustering in the MANET

The protocol needs to generate non-overlapping clusters, i.e. each node is member of at most one cluster at the same time. Otherwise, the routing and addressing mechanisms would have to deal with the situation of multi-homed nodes. This is not the primary goal, as it leads to increased complexity .The clusters should be the basis for hierarchical routing .By using an auto-configuration mechanism, address prefixes are assigned to the clusters. The address prefix for a cluster is maintained by the CH. Each node in a cluster has to know its address prefix. From this requirement, it follows that only the cluster members need to know their current CH, but not vice versa. We assume that each cluster can be identified network-wide by some unique value assigned to it. This unique value could for example be the cluster head's MAC address. Consequently, a node can be in four different states: It can either be no member of any cluster (un-clustered), member of exactly one cluster (clustered), the CH of exactly one cluster (CH) or have another role (guest node). As a result of the nodes' movements, there are several possible events in the life cycle of a cluster (see Figure 1).

Two nodes may meet and form a cluster, one of them declaring itself to be CH (event create). Nodes can be added to an existing cluster (event join). Or two clusters may be collapsed to one (event merge). If a cluster is split in two with one of the remaining parts having no CH, the cluster has to be "repaired" accordingly.

Nodes may depart from their clusters (event leave), and a cluster disappears when all members leave it.

The last and most significant requirement for ODGM/GN is that it has to be reactive. Most of the clustering protocols previously proposed in the literature try to (pro-) actively discover a node's neighborhood by periodically broadcasting "hello-beacons". By counting the hello's received from various nodes over longer time spans, it is possible to draw conclusions about the physical proximity of nodes .ODGM/GN aims to demonstrate that passive (reactive) monitoring of the data traffic is sufficient to detect node neighborhoods.

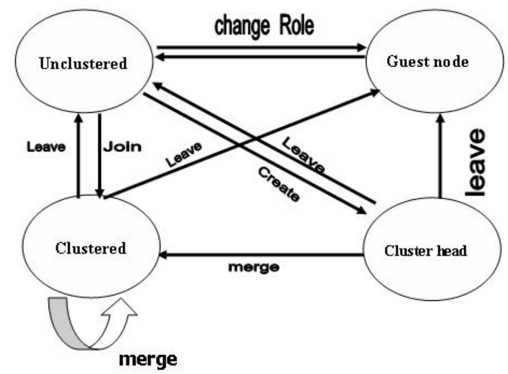


**Figure 1. Finite-State Machine For Group Mobility-Based Clustering**

### *A. Proactive Clustering*

GMBC First, ODGM/GN's precursor is described briefly. This protocol, Group Mobility-Based Clustering (GMBC) is quite simple, therefore suitable for an introductory view on clustering with group mobility and lending itself to comparisons of experimental results. With GMBC, nodes periodically broadcast hello-packets.

The packets are overheard by nodes within radio range. Every "hello" received from different neighboring nodes is counted. If the number of hello-packets from a specific node exceeds a configurable threshold value (with some allowable packet loss to account for undetected MAC layer collisions; see [16] for a discussion of this problem), that node is regarded as a neighbor. Up to this point, the procedure is quite similar to Toh's Associativity Based Routing (ABR) [17]. A node declares itself to be a cluster CH if it has had neighbors for a certain time span (another configurable threshold value). The declaration is made by broadcasting a create-packet (event create in Figure 1). All nodes which receive this packet check whether it was sent by one of their neighbors. If this is the case, they assume to be part of a group themselves and hence join the advertised cluster (event join). The joining nodes re-broadcast the .create.-packet in order to disseminate the cluster information over multiple hops. Propagation is limited through a hop counter field in the packet. The hop counter (which is unrelated to the TTL field in the IP header) is decremented after each hop, stopping the forwarding when it reaches zero. It is required because GMBC uses application-layer forwarding. The cluster structure needs to be maintained due to the nodes' mobility. A soft-state approach was adopted. The CHs have to refresh the cluster state periodically. They do so by broadcasting a new .create.-packet. To save bandwidth, this packet replaces the cluster head's hello-packet and is sent with the same frequency. Clusters merge if two CHs get in reach of each other: The CH with the smaller identifier, i.e. the lexicographically smaller MAC address, continues to be CH, the other one gives up. All nodes in the fading cluster will join the persistent cluster when they first hear its cluster head's "create"-beacon .In GMBC, all nodes only know their respective CHs .They also change their clusters whenever they overhear a new (or previously unknown) CH. This has severe implications for the overall cluster stability. In the evaluated scenarios, the average rate of nodes changing their clusters was about five times higher than with ODGM/GN. Regarding to the address auto-configuration and routing, this instability leads to many route failures.

*B. Reactive Clustering*

The goal of reactive protocols is to reduce protocol overhead when their function is not currently needed. In our case, this means that the signaling traffic should be kept as minimal as possible when there is no traffic flow in the network. No clusters are needed during these periods because hierarchical routing will not be used when there are no packets to be routed anyway. In this case, there will only be no traffic if a reactive routing protocol, such as AODV, is used. Also note that the routing hierarchy is more beneficial with multiple concurrent end-to-end connections in the network .The problem of reactive clustering can be split in two parts. First, it has to be detected when there is the need for clustering, i.e. when traffic flows. Then, which nodes participate in traffic flows, clusters have to be established and maintained. These two parts can be regarded as two completely different protocols with strictly defined interfaces (Figure 2). In particular, the protocols described afterwards are the Neighborhood Recognition Protocol (NRP) and the clustering protocol itself.

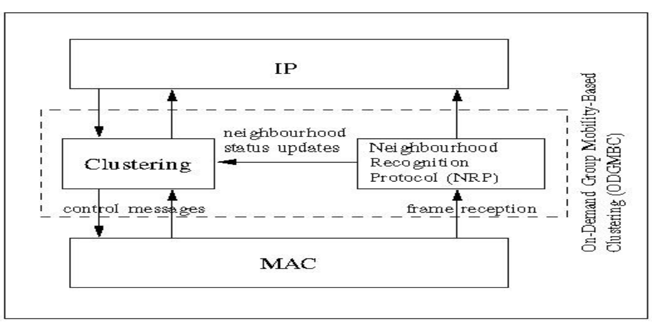


**Figure 2. Position of NRP and ODGM/GN in the protocol stack**

## 3. Proposed Approach

Using NRP and node monitoring, it could be known which node is suitable as CH. However, as the neighborhood recognition only works in one direction, the detected neighbors have to be informed of their detection. Informing the neighbor also helps detecting unidirectional physical links. The notification was implemented in two ways: First, if the monitoring node has to send an IP packet to the detected neighbor anyway, a special IP option is placed in the packet header. Second, the detection of neighbors is announced by broadcasting special "NEIGHBOUR-INFORM"-packets. As it is very likely that many neighbors are detected in rapid succession, the MAC addresses are held in a queue which is flushed after a (short) predefined time interval. Such a situation is likely to occur when a reactive routing protocol is used. In the initial route discovery phase, a node may detect the presence of multiple neighbors. By using a queue and bundling all the detected nodes' MAC addresses into one broadcast message, bandwidth can be conserved .Every node keeps record of detected nodes and nodes which detected itself in two separate lists. The neighborhood graph defined by the NRP and the "NEIGHBOR-INFORM" messages forms the basic structure for our clustering algorithm.

Only the nodes which are contained in this graph participate in the clustering process. Therefore, if all traffic measurements fall below NRP's threshold value, no neighbors are detected and no clusters are built. This exactly was the primary goal.

We adopted an approach similar to Random Competition based Clustering .Whenever a node detects its first neighbor; it waits for a random time interval (drawn from a uniform distribution). If no other node in its vicinity has declared itself to be CH within the time interval, it does so itself. Note that, only nodes which have recognized other nodes as neighbors by themselves are allowed to make a CH declaration. This is done by flooding a LEADER-BEACON message. The LEADER-BEACON is forwarded only by cluster members. Its propagation is limited by a hop counter in the packet header. Let the maximum propagation distance be denoted by k. Then k-hop clusters are formed. We will refer to k as the maximum cluster radius in the following text .With RCC, conflicts may arise during the CH election phase. Ties in CH competition are broken as follows: If two nodes within mutual distance of less than or equal to k hops declare themselves to be CHs simultaneously , the node with the lexicographically smaller MAC address has to give up and become cluster member. By the same method, cluster mergers are performed: If two groups cross their ways, they will eventually be merged into one.

Each node records the LEADER-BEACONs it has seen, but sticks to its current CH as long as possible. A node in the un-clustered state (and having neighbors) enters the cluster of the CH it hears first. State is preserved through a soft-state mechanism: The CHs periodically have to re-broadcast their LEADER-BEACONs. In case a node has not heard of its current CH for a prescribed time period, it immediately switches its membership to the cluster whose CH has the minimum distance to the node among all known CHs. In case there are no other CHs, but the node still has neighbors, it declares itself CH. Cluster partitions are repaired this way.

Otherwise, the node leaves the cluster by changing back to the un-clustered state. The destruction of a cluster is determined by all nodes leaving it. NRP was modified as not to count the control messages sent by the clustering protocol. Otherwise, clusters would not be destroyed when there is actually no more traffic. This is because the clustering protocol keeps sending beacons as long as there are neighbors (as recognized by NRP) which ought to be clustered.

## 4. Experimental Results

To evaluate ODGM/GN's functionality and performance, a prototype module for the ad hoc network simulator NS v2.29 was used. The deployment scenario is a pedestrian precinct. There are 300 pedestrians (nodes) dispersed over a quadratic area measuring 2000 m * 2000 m. Each pedestrian is equipped with an 802.11-capable device having a radio range of 250 m. The node speed ranges from 0.5 m/s to 2.0 m/s. A total of 215 nodes move individually, whereas the remaining 85 nodes are divided among six groups with diameters from one to three hops. Reference Point Group Mobility (RPGM) model [30] is as the mobility model. The group centers move according to the Random Direction. Model [18], with the mean epoch time set to 30 seconds. Individual motion is also generated using the RPGM model by creating groups with only one node. These nodes' positions and movements are identical to those of the respective group centers. Network traffic is generated using a simple model: There is a fixed number of connections with fixed endpoints (per simulation run). Connection endpoints are chosen independently and identically distributed (i.i.d.) among all 300 nodes using a uniform random distribution. The connections start uniformly i.i.d. within the first 20% of simulated time, which was chosen to be 300 seconds (5 minutes). They stop simultaneously with the simulation. Over each connection, packets of 512 bytes length are sent with a constant rate of two packets per second from the first to the second endpoint. A load of 30 concurrent connections was put on the network, resulting in a maximum packet loss of 5%, which was confirmed in additional simulation runs. AODV is used as the routing protocol .All results are averaged over the resulting 90 simulation runs, leading to reasonable statistical significance with comparably low simulation costs. Although they may be chosen independently, the period length of the NRP and the period length of the CH beaconing were set to equal values, respectively.

This decision will be re-evaluated in our future work, but the independent choice has the drawback of multiplying the non-negligible simulation costs with another factor ODGM/GN was simulated with period lengths of 5 s and 60 s. For comparison, GMBC was simulated with the respective parameters set to reflect period lengths of 5 s and 30 s. In both cases, the maximum cluster radius was set to be 3 hops. To recognize a node as a neighbor, one received packet per 6 seconds suffices.

The number of CHs in the network and the average size of clusters give hints whether the protocol works properly. As mentioned before, cluster stability is of high importance for the targeted application, namely automatic addressing and hierarchical routing. Therefore, the change frequency of CHs and cluster members are additionally inspected. The duration of nodes being in the CH state and the brief sojourn in different clusters also help in evaluating cluster stability. Also, the overhead incurred by the clustering protocol has to be measured.

Compare the number of CHs and average cluster size (mean number of cluster member) with ODGM/GN as opposed to those of GMBC with the same period (see Figure 3 and 4). The slowly ascending curve showing ODGM/GN's average cluster size suggests that the protocol works as expected: It reacts to the increasing traffic load. Compared to GMBC, the curve showing the number of CHs with ODGM/GN is considerably smoother. This is a first hint that cluster stability is better with ODGM/GN than with GMBC .The peak at the beginning of GMBC's CH curve is the result of a large number of CH election conflicts. They arise because all nodes nearly simultaneously begin clustering. Due to the high variability, clusters tend to be smaller and more CHs are present than with ODGM/GN.

Comparing the CH change frequencies in both configurations (see Figure 5 and 6), it becomes obvious that GMBC performs considerably worse (2.05 changes/second) than ODGM/GN in this point (0.36)

Also see table 2 regarding stability and overhead. There is a simple explanation for the high stability of clusters with ODGM/GN. Other than with GMBC, nodes "stick" to their CHs as long as possible. They only change their clusters when their previous CHs' beacons have not been overheard recently. Also in contrast to GMBC, not every node has the ability to declare itself CH in ODGM/GN. Remember from section I that only nodes which have recognized other nodes as neighbors themselves are allowed to do so. Because nodes keep a list of recently overheard CHs, they can immediately join an existing cluster when they need to. With GMBC, nodes do not keep a comparable list and therefore always create a new cluster in these situations. Many conflicts arise due to this design decision.

Regarding the cluster change frequency, ODGM/GN again clearly outperforms GMBC (see Figure 7 and 8). The same reasons as for the CH change frequency apply here.

The less often status updates are made (i.e. packet are sent), the less often the state actually changes (i.e. nodes change their clusters). The longer the periods are, the more the risk of having stale state at the nodes increases. There is an obvious trade-off between the update frequency (which clearly is correlated with the generated overhead) and the actuality of state.

Compared to GMBC, ODGM/GN's overhead is slightly higher in the tested scenario. This mainly follows from the high overall traffic load. As ODGM/GN is a reactive protocol, the overhead should be proportional to the network load.

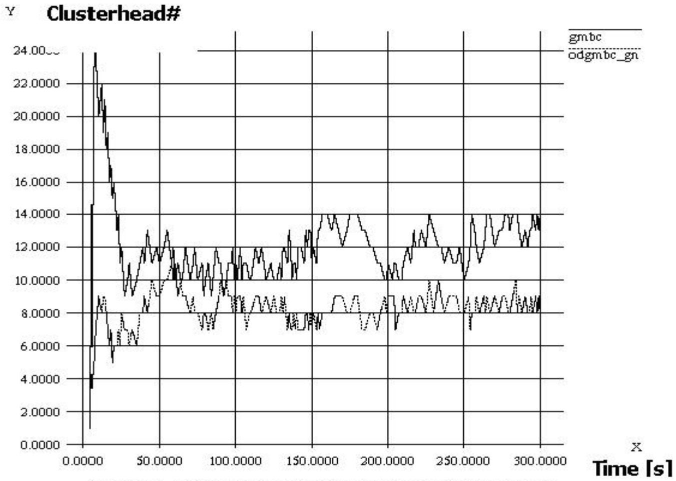


Figure 3. Number of CH (GMBC and ODGM/GN)

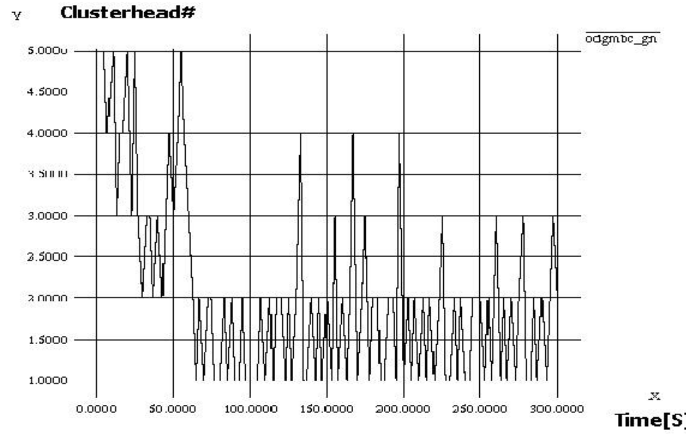


Figure 6. Change CHs per Second in ODGM/GN

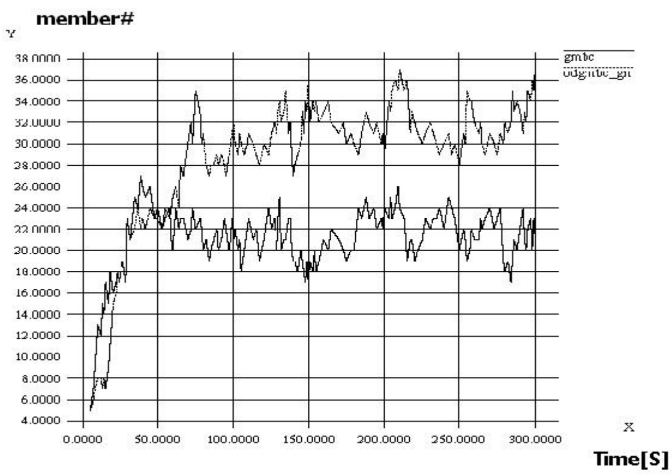


Figure 4. Mean Number of Cluster Member (GMBC and ODGM/GN)

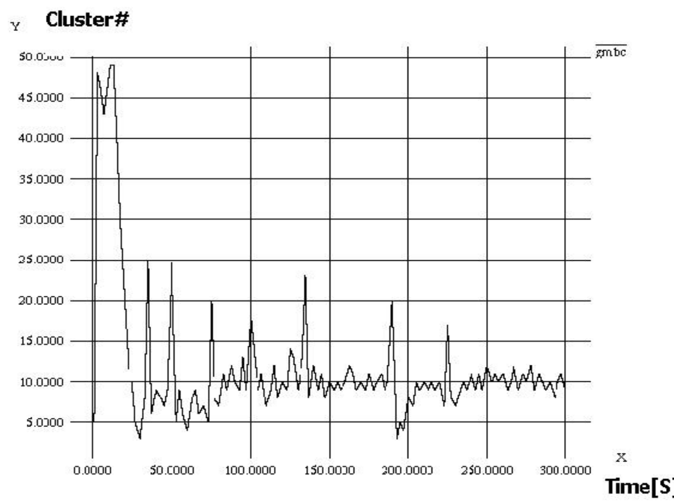


Figure 7. Cluster Change per Second in GMBC

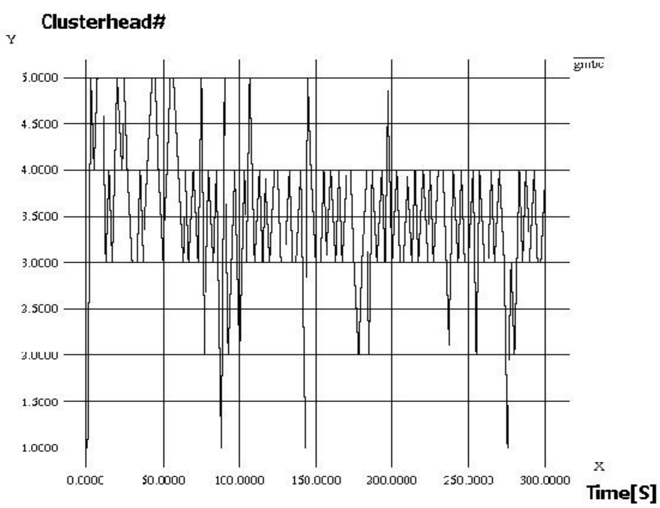


Figure 5. Change CHs per Second in GMBC

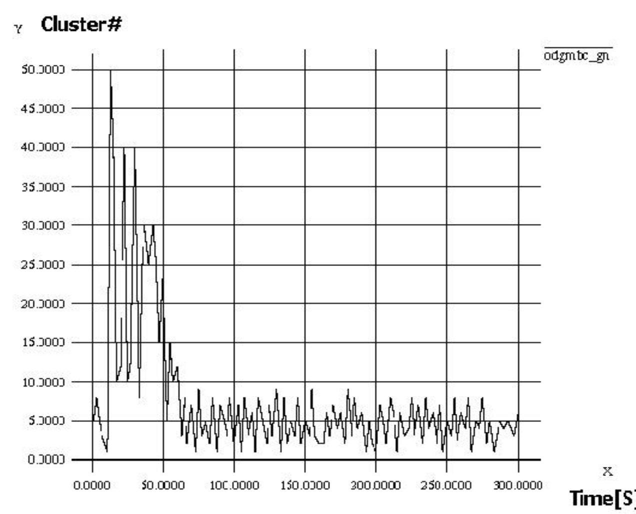


Figure 8. Cluster Change per Second in ODGM/GN

**Table 2. Simulation Results: Stability and Overhead**

| configuration | Cluster Change # | CH change [1/s] # | Average CH Stability [s] | Cluster Sojourn [s] |
|---|---|---|---|---|
| GMBC[ 5s] | 7.38 | 2.05 | 15.06 | 26.84 |
| ODGM/GN [5s] | 1.58 | 0.36 | 46.16 | 97.25 |

ODGM/GN has to send more messages than GMBC because of its neighborhood detection scheme. Also, these messages are quite long because the MAC addresses of the recognized neighbors are appended. In the scenario, nodes have 15 neighbors on average and MAC addresses are 48 bits long.

To sum up, our simulation results indicate that ODGM/GN is working as desired. It reactively builds clusters of high stability. In its current design, protocol overhead is a drawback in dense traffic scenarios due to the neighborhood detection scheme, but some ideas to reduce it are outlined in the last section.

## 5. Conclusion

In this paper, we have investigated the feasibility of reactive clustering protocols with group mobility. A possible solution has been presented. It could be shown that the approach indeed yields stable clusters. Table II gives an overview of the stability and overhead for the configurations. What's more, it can be seen that ODGM/GN is much better than GMBC in terms of the cluster sojourn time in clusters. Statistically, the significance of the difference could not be rejected at an error level of 5%. For both protocols, the increase of the period durations leads to generally better performance indicators. Finally, the created clusters will have a better stability and results less re-clustering and overhead.

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