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2-hop Clustering to accomplish semi-static structure in MANETs

Hatem Hamad
hhamad@iugaza.edu.ps

Abstract: Most researches today trend to clustering in ad hoc networks for building hierarchies to solve management problems in flat architectures. Clustering aims to elect suitable nodes as representatives to lead the network, called Cluster Heads (CHs). Frequent topology changes occur due to nodes mobility and failure. Although re-clustering is invoked to maintain the clusters, many cases involve destroying the cluster when the CH moves to another region or fails and hence building new cluster/s is needed which negatively affects the stability of the network and its ability to provide services. In this research, I developed a 2-hop clustering solution to accomplish a semi-static structure. This is accomplished by reassigning the CHs according to the number of 1-hop neighbors. The node that has the highest number of 1-hop neighbors that are in the 1-hop range of the CH has the highest connectivity with the members and hence it is the best node to replace the CH when moves or fails. Simulation results show accomplishing semi-static structure and enhancing the performance of the ad hoc network.
Keywords: Ad hoc networks, Cluster, Connectivity Number.

تجميع أجهزة المحمول لتحقيق هيكلية شبه ثابتة في شبكات المحمول الديناميكية

ملخص: شبكات المحمول الديناميكية هي أحد أنواع الشبكات اللاسلكية التي تتكون بطريقة ديناميكية دون أي إعدادات مسبقة و دون الحاجة الى أجهزة مركزية. عمد العديد من الباحثين إلى بناء هيكلية لهذا النوع من الشبكات عن طريق تجميع الأجهزة في مجموعات بحيث يكون لكل مجموعة جهاز مسئول عن إدارتها يسمى مدير المجموعة و يتم اختياره بطريقة ديناميكية. و تبعا لخصائص هذه الشبكات من حيث الحركة الدائمة والعشوائية للأجهزة المتصلة فإنه ينتج على تركيبة هذه المجموعات تغييرات جوهرية مما يعيق استمرارية عمل هذه الشبكات إلى حد انهيارها في بعض الأحيان. في هذا البحث قمت بتطوير بروتوكول بهدف الوصول إلى هيكلية شبه ثابتة ومستقرة للمجموعات المكونة للشبكة. فكرة عمل هذا البروتوكول هي إعادة إسناد مهمة إدارة المجموعة بشكل دوري إلى الجهاز الذي يتواجد في مركز المجموعة تقريبا عندما يبدأ المدير السابق بمغادرة هذه المجموعة. تدل نتائج هذا البروتوكول على تحسن أداء عمل شبكات المحمول الديناميكية.

1. Introduction

A mobile ad hoc network is a collection of wireless nodes that dynamically form a network without any pre-existing infrastructure or pre-defined topology. In this network environment, each node acts as an information source as well as a router to relay packets to its neighbors [1]. The network is fully autonomous and can be formed at any time. It is characterized by limited battery power, limited bandwidth, frequent network topology changes, and rapid mobility. Frequent topology changes result when nodes move or fail or when devices are turned on or off. These characteristics make the design of management solutions and routing protocols a great challenge. Flat MANETs structures encounter scalability problems especially with the increased network size. In these architectures, each node has to maintain information about all nodes in the network, which becomes significantly large with increasing the network size [2]. Most researchers today focus on dividing the network into clusters. Each cluster has a representative known as a Cluster Head (CH). Every node has to join to a cluster. Nodes that belong to more than one cluster are called Gateways and other nodes are called Members as in figure 1.

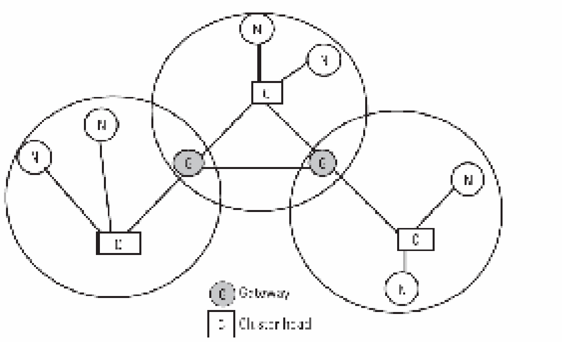


Figure 1. Clustered Ad hoc Network

Some clustering techniques eliminate the need for CH and adopt fully distributed algorithms for cluster formation [5]. Clustering provides several advantages in mobile ad hoc networks. Grouping the nodes improves routing and management [3][1]. It reduces network bottleneck, congestion, and the amount of information at each node, therefore makes the network more scalable. Also, clustering helps to form a topology for dynamic network which makes the network more stable [4][6]. Clustered ad hoc networks are classified as one-hop or multi-hop. In one-hop networks a member mobile node uses single hopping to reach the CH while in multi-hop networks a mobile node uses multi-hopping to reach the CH [7][8]. In order to gain the benefits of clustering in MANETs and employ these dynamic networks in civil and/or military applications, it is important to preserve the structure of the network as much as possible taking into my consideration nodes mobility and failure. Based on the above ideas, I propose a 2-hop clustering topology to accomplish a semi-static structure of ad hoc networks.

The rest of the paper is organized as follows; section 2 provides State of the art and section 3 defines the problem statement. Section 4 introduces my proposed solution and section 5 discusses the simulation results. Finally, section 6 concludes the paper and proposes future work.

2. Problem Statement

Mobility is a main factor affecting topology and route invalidation in MANETs. In clustered ad hoc networks, the manager node, CH, is responsible for many jobs such as maintaining the cluster, updating the routing tables, and discovering the new routes. Failure or loss of the CH will destroy the cluster. Mobility may cause CH loss while failure may be due to power exhausting. In this section, I will show the problems caused by CH mobility, loss, and failure. Most of the current clustering algorithms define complex computations and frequent information exchange among nodes which results in high cost in CH selection, cluster construction, and cluster maintenance.

1. High Mobility problems

High mobility nodes are inadequate to be assigned as CHs since their movement will cause frequent and serious topology changes. The main problem with high mobility CHs is that they are subjected to loss. When the CH leaves the cluster due to its high speed, the cluster will be destroyed and the commutative information held on the CH will be lost. Then the clustering algorithm has to be invoked to build a new cluster with new structure information. The next CH will be elected according to the criteria defined in the clustering algorithm. This means that the next CH may be in a position that is away from the old CH position, which leads to significant and serious structure changes. This scenario is repeated frequently with high mobility CHs which leads to exhaust the network resources especially energy and bandwidth due to processing overhead and frequent control messages exchanging [9].

1. Low Mobility problems

With low mobility, I mean that the CH moves within the 1-hop range. Although the CH will not be lost, many disadvantages will result in with low mobility; (1) frequent topology changes occur which adversely affects the network stability. (2) Frequent movements lead to increase the flooding of control packets and hence exhausting the limited resources of the system. (3) The responsibility of the CH for maintaining the cluster means that the CH remains in his role for a long period. This increases the power consumption on the CH and hence increasing the possibility of failure.

I. CH failure

According to characteristics of MANETs, nodes are subjected to power failure since they work on battery power. CH failure, due to power exhausting or device shutting down, will destroy the cluster and management information held on the CH will be lost. Many clustering algorithms have been designed considering energy saving [11]. These algorithms reduce power consumption and accomplish power control for ad hoc networks, but this does not prevent sudden failure. Therefore, it is important to develop a solution to keep the management information, as much as possible, in case of CH failure.

3. Related Work

Many algorithms have been proposed to build and maintain clusters in ad hoc networks but almost all of them fail to guarantee a stable cluster formation. Cluster-Based Routing Protocol (CBRP) is a routing protocol that clusters the network to reduce the flooding of control packets. CBRP groups the nodes in clusters and elects a CH for each cluster. At any time, a node is in one of three states: a cluster member, a cluster head, or undecided, meaning still searching for its host cluster [14][15]. Each node starts in the undecided state and periodically broadcasts a Hello message. Upon receiving a Hello message, the CH responds to the node and joins it to the cluster. The node then changes its state to member.

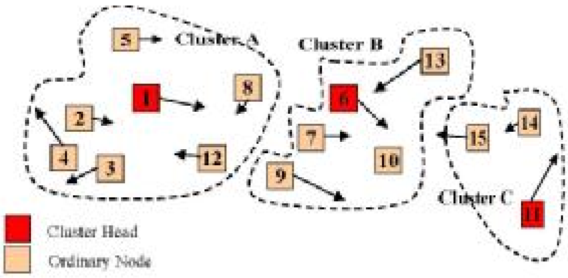
The lowest ID (LID) is a simple and quick clustering method [5]. Nodes with smaller IDs are highly likely to be CHs. The main drawback is that it does not care about the mobility of CHs. The CH keeps its role for long period, which may lead to power failure and then structure destruction. In addition, when the CH moves it may unnecessarily replace an existing CH causing topology changes.

2-hop Clustering to accomplish semi-static structure

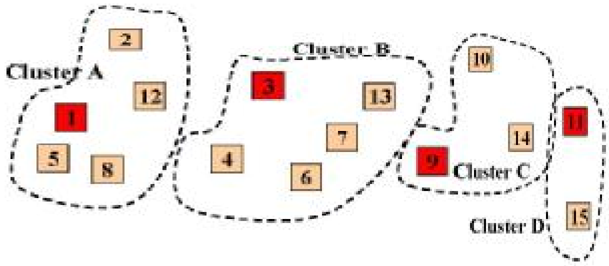
Gavalas and his co-workers proposed many clustering algorithms to achieve stable structure and reduce flooding of control packets in MANETs. In Ref. [16], they introduce a clustering algorithm that adapts the Hello Period, i.e. broadcast period BP, to reduce the flooding of control packets. The CH is responsible on adapting BP according to nodes' mobility pattern. For high mobile nodes, the CH informs the members to shorten the BP to maintain more accurate information about topology. When the mobility rate is low, the BP is lengthened to reduce flooding of unnecessary control packets.

In Ref. [17], the authors propose a mobility aware technique for clustering the ad hoc networks. The purpose is to avoid the disadvantage of frequent CH changes in the HD algorithm [18]. Each mobile node computes a weight that has a large value if the mobile node has large number of neighbors that will remain in its neighborhood for a long time with mobility. Therefore, a node with largest weight is most suitable to be elected as a CH to obtain more stable cluster.

LIDAR algorithm proposed in Ref. [9] explicitly separates cluster formation and cluster maintenance phases. CHs are initially elected based on the time and cost-efficient lowest-ID method. During clustering maintenance phase, nodes IDs are reassigned according to nodes mobility and energy status, ensuring that nodes with low mobility and sufficient energy supply are assigned low IDs and hence, are elected as CHs. However, reassigning CHs here will cause significant topology changes resulting in destroying the existing clusters and forming new clusters, which lead to overhead, information loss, and exhausting resources, figure 2. However, among the above algorithms, LIDAR algorithm performs best. Therefore, in figure 10, I compare my results with those reported in the LIDAR algorithm.



a. Current Clustering status



b. Re-clustering of mobile nodes

Figure 2. Completely new topology

The Weighted Clustering Algorithm (WCA) [10] considers a number of metrics such as node degree, CH energy, and moving speed to calculate a weighted factor I_v for every node V. Mobile nodes with minimum Iv are elected as CHs. Although this algorithm helps to elect suitable nodes as CHs, the CHs will remain in their roles for a long time, which lead to energy exhausting and failure causing overhead in re-electing new CHs.

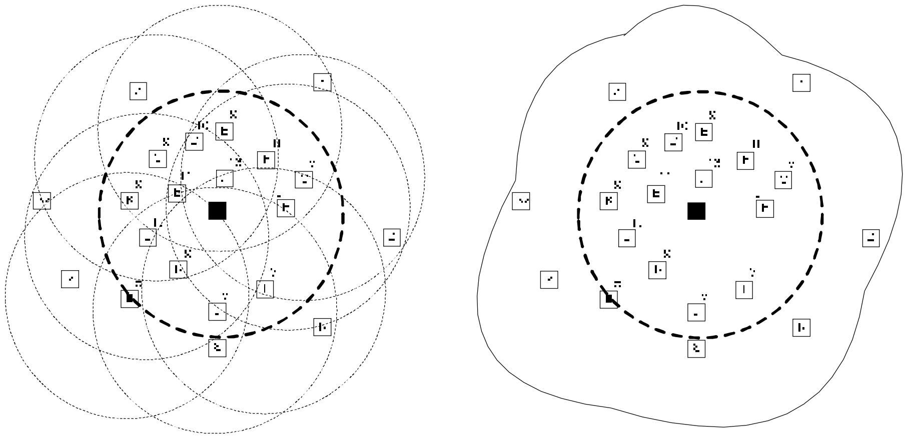
I believe that a good clustering method should preserve the structure of the network as much as possible with simple implementation and low overhead.

4. Proposed solution

In this paper, I propose a simple powerful algorithm for building 2-hop clustered MANETs that preserves the network structure as possible in high density MANETs. In 2-hop clustering, a mobile node may only use one other node to reach the CH and the range of the cluster results from the ranges of 1-hop nodes as in figure 3.

The main idea is to keep the structure of the cluster and avoid re-clustering as possible by electing the most suitable node as the next CH. In order to reach to semi-static structure I monitor the location of the cluster and the location of the

2-hop Clustering to accomplish semi-static structure



a. **1-hop cluster** **b. 2-hop**

Figure 3. Cluster range for 1- and 2-hop

CH. The member nodes determine the location of the cluster. With the next Hello message, I check whether the CH is still the best node to manage the cluster or not. If not, I select a node that has most knowledge about the cluster structure as the next CH. In my algorithm, the 2-hop semi-static approach provides the advantage that the number of lost nodes due to CH mobility is reduced as shown in the simulation section, figure 8.

I. 2-Hop Clustering

Every node maintains a neighbor table (NT) that contains information about the neighbor nodes. Entries of the NT are node ID, role, CN, and the CH ID. Every node maintains a Boolean parameter that indicates whether it is a 1-hop with regard to the CH. This parameter is included in the Hello message. It is True if the node is a 1-hop member and False otherwise. The choice of 2-hop radius is suitable to ensure that reassigning the CH to a new node occurs smoothly, i.e. the new CH is elected before the old one leaves the cluster. To clarify this, let's assume high mobility pattern with speed up to 40 m/s. The radio transmission range is 625 m and the Hello period is 2 sec. [14]. As shown in figure 4 the maximum cluster range is 625 m. Then, the old CH will leave the 2-hop range in about 15 sec., which equals 7 Hello periods. Therefore, when the CH leaves the one hop range, there is still enough time to elect a new CH before the old one leaves the two-hop range. That is, except in case of CH failure, there is always a manager in the 2-hop cluster range. In addition, based on the above calculations, we can increase the Hello period to 4 sec. reducing the number of Hello messages broadcasted. Then the old CH still exists 3 Hello periods in the cluster which are sufficient to elect a new CH. An advantage of the 2-hop cluster is that, although a new CH is preselected, all nodes, which are not anymore 1-hop distance, remain members in the cluster, because they are 2-hop nodes and thus do not need to look for a new cluster.

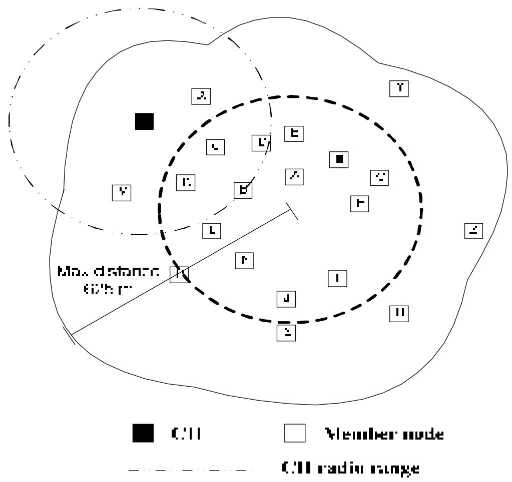


Figure 4. 2-hop range in meters

II. Connectivity Number (CN)

A node connectivity number is the number of its 1-hop neighbor nodes with regard to the cluster head. The node connectivity number is the value, which we maintain, to form the decision, whether the preceding CH is the best node to hold as a CH or there is now a more suitable one. Instead of shifting, the cluster with the CH, we replace the CH with the node, which has the highest CN. A node is closer to the center of the cluster, if its CN is higher. Each node broadcasts regularly a Hello message, which includes its neighbor table (NT). Hello message also contains additional information, the CN, and the Boolean parameter, which indicates whether the sender node is a 1-hop. Based on Hello messages a node calculates its connectivity number. The member node stores the received Hello messages in a queue. There are two alternative methods to calculate the CN. The first based on the NT of the CH. Upon receiving a Hello message from the CH, the member node iterates the NT of the CH and compares each entry with its NT entries counting the matching entries. The second method is to access the Boolean parameter of the received Hello message. If the Boolean parameter is true, the CN is incremented. The second method is more efficient because the node will not need to compare between the two tables. Figure 5 shows node M with CN equals 8 since it has 8 neighbors fall in the 1-hop range of the cluster (in the intersection area).

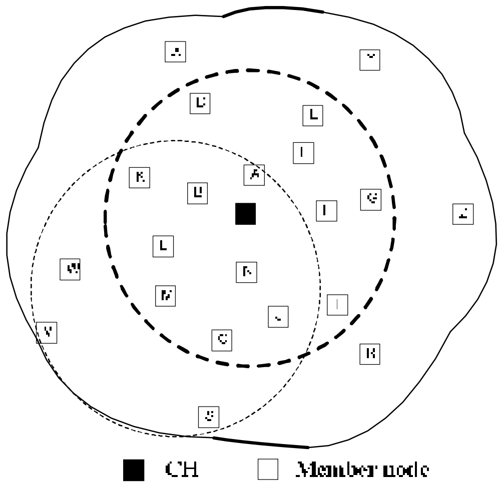


Figure 5. Node M has CN = 8

III. Algorithm

Figure 6 shows a pseudo code of my algorithm, which involves the following steps:

1. Clusters formation

At startup, nodes are grouped in clusters according to any criteria, i.e. any clustering algorithm can be used to initially build the clusters. In CBRP, Each node starts in the undecided state and periodically broadcasts Hello messages. Upon receiving a Hello message, the CH responds to the node and joins it to the cluster. The node then changes its state to member. Nodes still send Hello messages every Hello Period (HP) to inform its neighbors that it is alive.

2. Calculating CN

In each HP, upon receiving Hello messages from its neighbors, each node stores these Hello messages in a queue. Then each node iterates the queue to calculate its CN. The CN is a measure of the closeness to the cluster center. A node is closer to the center of the cluster, if its CN is higher. Therefore, to keep the cluster semi static and not to move the cluster with the movement of a constant cluster head, dynamically we select the node with the highest CN to be the new cluster head.

3. Broadcasting Hello messages

Periodically, each node broadcasts a Hello message, which involves the NT, the CN, and the Boolean parameter. All the entries of the NT are included in the Hello message. The neighbors benefit from the NT to collect information about the topology.

4. Reassigning the lost CH

Each 1-hop node broadcasts its CN with the next Hello message. Then, each node compares its CN with the received CNs. The node with the highest CN will declare itself as the new CH. The old CH completes its current job and then becomes an ordinary node. By this way, a new CH is declared only if the CH moved away from the cluster center. Otherwise, the CH remains the manager of the cluster. If two nodes declare themselves as CHs, then when receiving the next Hello message each of them compares its own CN with that of the other CH's. The one with the highest CN will continue to act as CH. In case of the same CNs, the node degree (i.e. Number of the neighbors) is regarded, in order to select the CH. With selecting the CN, if 2 nodes with the same CN the node with highest degree is declared as CH.

5. Reassigning the failed CH

When the CH fails, member nodes will discover this failure in the next Hello interval since no Hello message will be received from it. Then member nodes will exchange the CNs with the next Hello message, compare the CNs, and the highest-CN node will declare itself as the new CH.

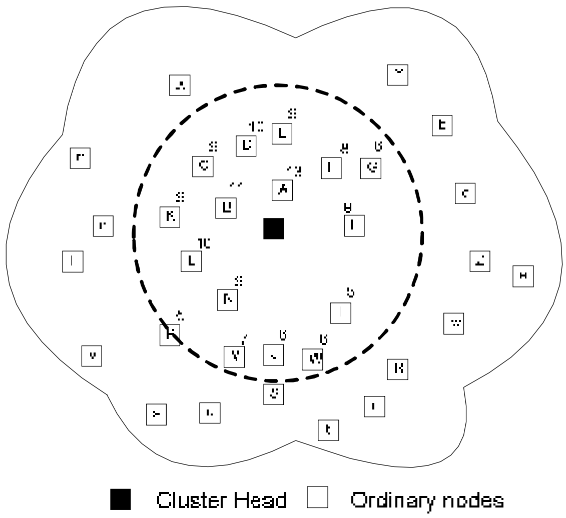
2-hop Clustering to accomplish semi-static structure

```
• Initialize

Group nodes in clusters
Initialize myCN to 0
if 1-hop node
   Initialize booleanVar to true
else
   Initialize booleanVar to false
endif
set HP to 4 sec
Initialize HP_timer to 0
SendHelloMessage (my_ID, myCN, booleanVar, my_role)
Start HP_timer

• Main processing

while HP_timer < HP Do
   receive Hello Message
   if the received Hello message is new
        Add msg to queue
   endif
endDo
while queue is not empty Do
   receive Hello message from queue
   if the booleanVar of the received Hello message is true
        increment newCN
   endif
if myCN > CN of the received Hello message
   set newRole to CH
elseif myCN = CN of the received Hello message
   if my degree > the degree of the received Hello message
        set newRole to CH
   endif
endif
endDo

if (newRole = CH && my_role != CH)
   set my_role to CH;
Else if (newRole != CH && my_role = CH)
   Complete current job
   set my_role to MEMBER
endif

set myCN to newCN
if 1-hop node
   set booleanVar to true
else
   set booleanVar to false
endif
sendHelloMessage (my_ID, myCN, booleanVar, my_role)
set HP_timer to 0
set newCN to 0;
Start HP_timer
```

Figure 6. semi-static Algorithm

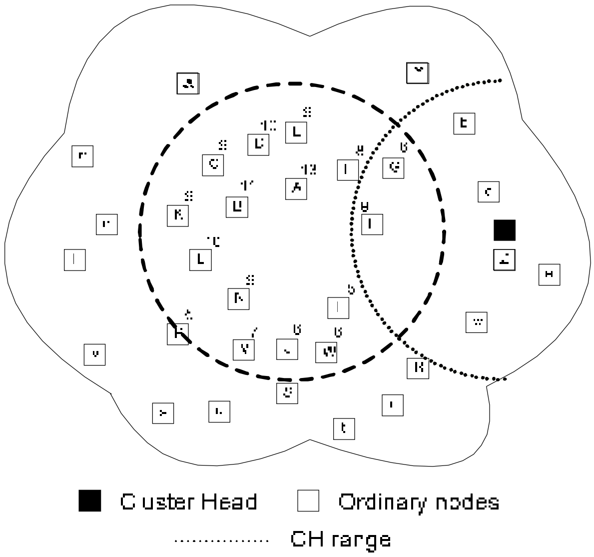
The advantage of this idea is that I do not need to build a new cluster or perform frequent re-clustering when the CH moves or fails; I only assign the most suitable node as the new CH. Steps from 3 to 6 are repeated with the mobility of the CH and member nodes. High mobility nodes will leave the cluster while low mobility nodes will remain. After the network stabilizes, I will arrive to a situation in which I have a semi-static structure formed in dynamic environment.

The following example illustrates the algorithm. Figure 7 part a shows the initial placement of nodes after building the cluster and the corresponding CNs which are computed with receiving the Hello messages. The figure shows the CH has the highest CN. In figure 7 part b, the CH moves away from the cluster and its CN becomes lower than the highest CN, which is at node A. Here node A is the best to be the next CH. In figure 7 part c node A declares itself as the new CH. Note that although nodes J, P, V, and W has become outside the new 1-hop range, they still members in the cluster. They only need to set the Boolean parameter to False.

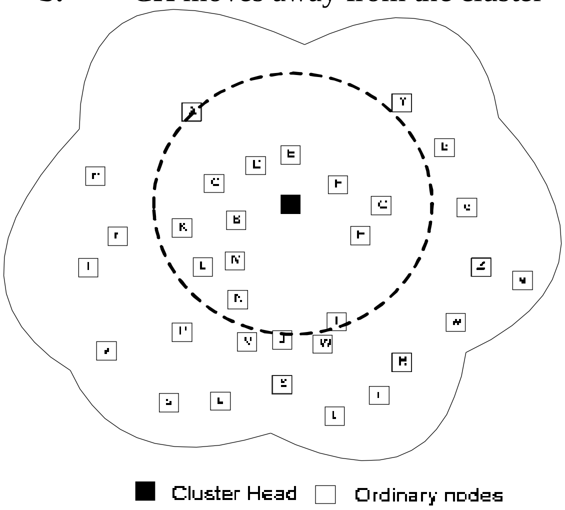


a. Placement of mobile nodes in the cluster. CH has the highest CN

2-hop Clustering to accomplish semi-static structure



b. CH moves away from the cluster



c. Node A is the new CH and the structure is nearly the same.

Figure 7. Example on algorithm steps

IV. Algorithm complexity

With every HP, the semi-static algorithm terminates in O(n) iterations where n is the number of Hello messages in the queue which equals the number of neighbors.

5. Simulation results

The performance of the semi-static structure algorithm is evaluated via simulations using JIST-SWANs simulator [12][13]. The simulation attempts to compare the performance of my clustering solution with CBRP [14]. My evaluation is based on the simulation of 50 mobile nodes to test the times that CHs lose members in 1 km2 during 5000 sec. in simulation time. The radio transmission range is 625 meters and two-ray ground propagation channel is assumed with a data rate of 1 Mbps. Random way point mobility model is used in my experiments with pause time of 4 sec. In this model, a node travels towards a randomly selected destination in the network. After the node arrives, it pauses for the predetermined pause time and travels towards another selected destination. The data traffic simulated is Constant Bit Rate [1]. 50% of the nodes generate 128-byte data packets every (20-25) second. I implement the algorithm as described in section 4. The node CN and the Boolean parameter are added to the Hello message. Each node broadcasts a Hello message periodically to maintain its NT. The Hello message is the only control packet used to build and maintain the cluster. The choice of these simulation parameters helps to test the solution in a dense heavy-loaded network. My solution outperforms the original CBRP in case of networks. To generate high load on the network, I choose a ratio of 50% of the nodes to transmit packets over limited bandwidth of 1 Mbps. The simulation attempts to compare the performance of my algorithm with the original CBRP [13] CBRP [14], LIDAR [9], LID [5], HD [18] and WCA [10] algorithms. These algorithms choose and justify the above parameters. Therefore, I also choose the above parameters to compare with them.

Figure 8 plots the times that CHs lose members with various speeds. The shape of the curve indicates that more nodes leave the cluster when the nodes' speed becomes high. At the speed of 20 m/s the times-of-loss decreases. However, the figure shows that loosing nodes is reduced significantly in my solution, which leads to more stable and more static structure.

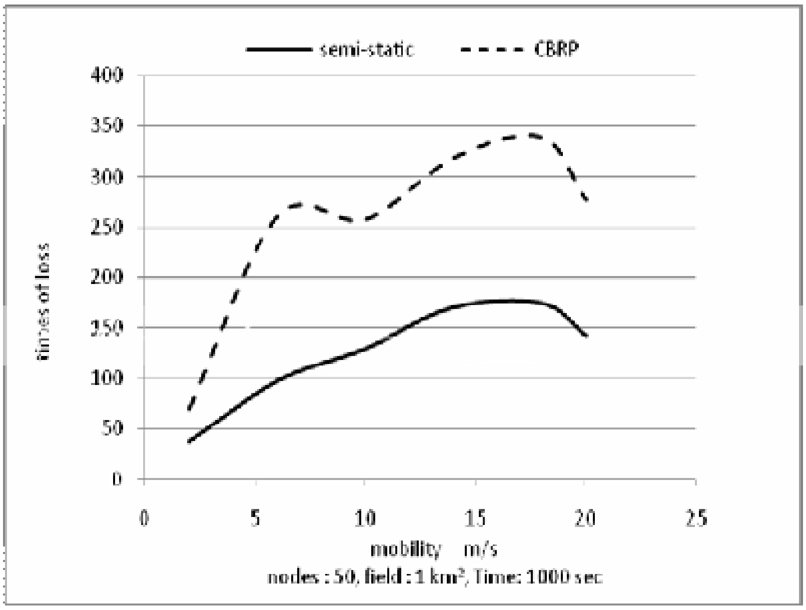


Figure 8. mobility vs. times of loss

Figure 9 plots the packet delivery ratio during the lifetime of the network for 5000s in simulation time with constant low speed of 2 m/s. The figure shows the packet delivery ratio is low at the start of the simulation since the network is in the formation phase. Once the clusters are formed, the network becomes more stable and the packet delivery ratio becomes semi-constant. The semi-static solution achieves a significant improvement in the packet delivery ratio. The high packet delivery ratio implies that the network is more stable since fewer packets are lost.

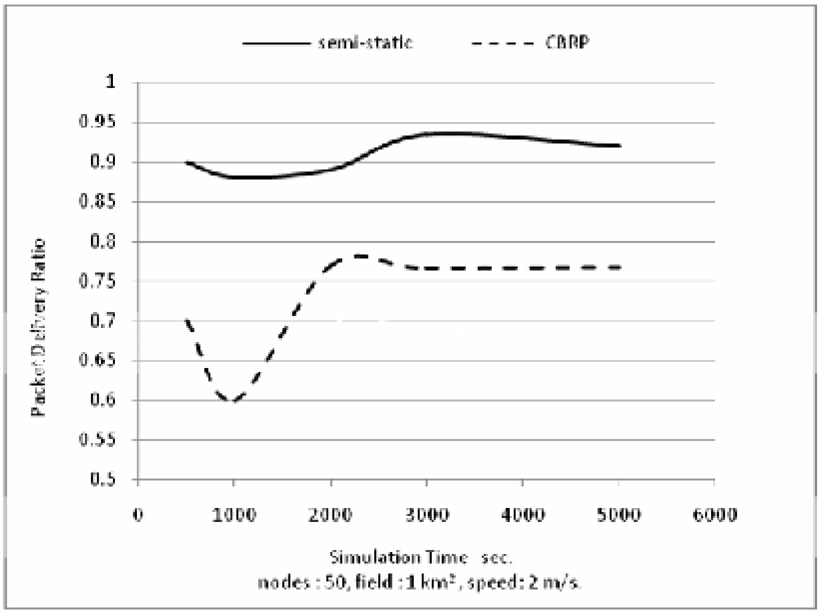


Figure 9. Packet Delivery Ratio vs. time

Figure 10 plots the packet delivery ratio with various nodes' speeds. It is clear that packet delivery ratio is high at low speeds. The ratio decreases with high speed, but in the semi-static algorithm, there is always an improvement.

Decrease, losing the members, and improving packet delivery ratio result from holding the cluster structure semi-static by reassigning the CH according to the CNs. Here, the CH mobility does not result in topology changes since the cluster head will reassigned nearly for the center of the cluster.

2-hop Clustering to accomplish semi-static structure

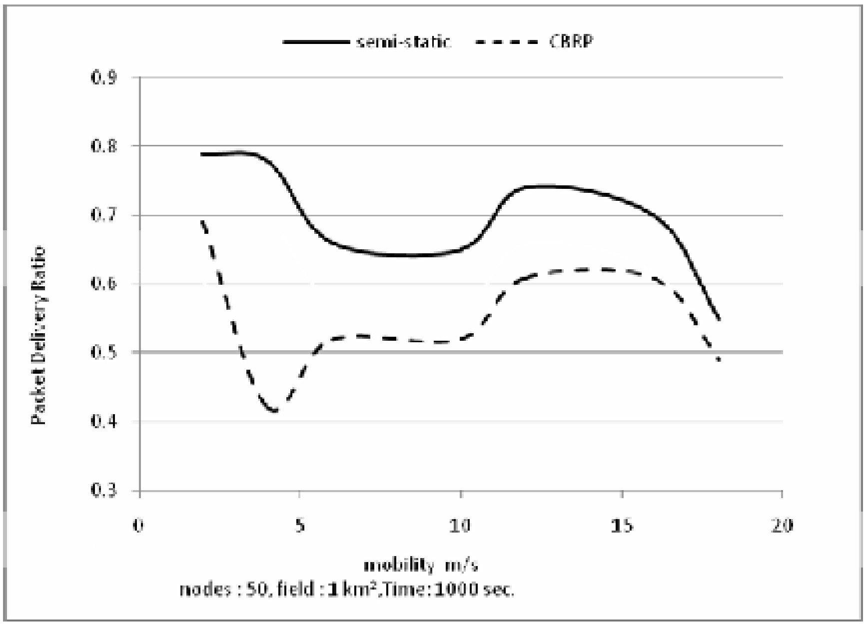


Figure 10. Packet Delivery Ratio vs. mobility

Figure 11 illustrates the overall control packets propagated through the network. I captured the results tested by Ref. [9], performed the test for the same parameters, and then merged the result in one graph. The test involved 50 mobile hosts move with average speed 0-15 m/s in a 600m × 600m. The Hello Period, frequency of broadcasting the Hello message, is 1sec. Each simulation runs for 3 minutes. The figure shows the semi-static algorithm outperforms the LIDAR algorithm at different nodes' speeds. This is because the semi-static algorithm avoids re-clustering by reassigning the CH and does not result in topology changes.

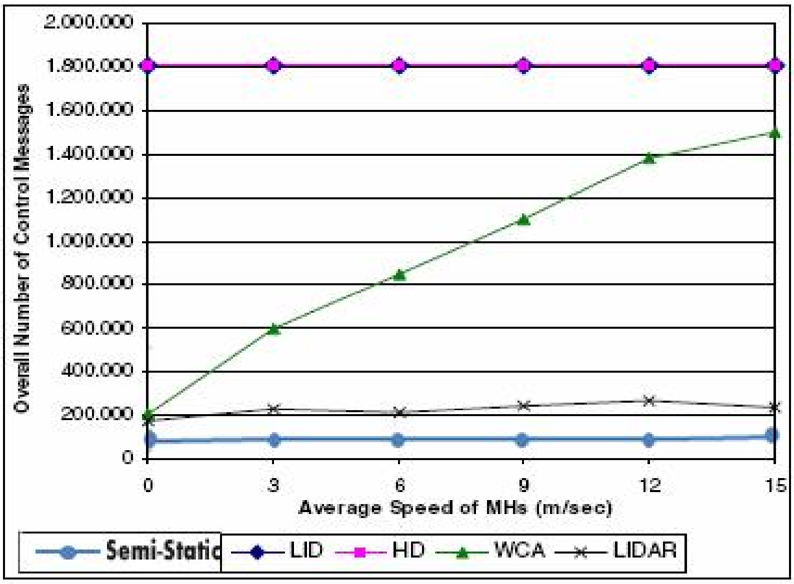


Figure 11. Overall number of control messages for 50 MHs.

6. Conclusion

In this paper I presented a 2-hop clustering scheme to preserve the structure of the cluster in MANETs as much as possible. To accomplish this I reassign the CH; the new CH is the node that has highest connectivity with 1-hop members. Simulation results show that loosing members is reduced and the packet delivery ratio is improved over time. These results demonstrate that this scheme accomplishes a semi-static structure, which results in more stable system and increases the system ability to provide the required services.

Finally, I would like to mention my future research direction. I will work on developing a solution to distribute the CH jobs between some member nodes to reduce the overhead on the CH.

Acknowledgement

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