A Novel Multi-hop Clustering Scheme for Vehicular Ad-Hoc Networks*

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ABSTRACT

Vast applications introduced by Vehicular Ad-Hoc Networks (VANETs), such as intelligent transportation, roadside advertisement, make VANETs become an important component of metropolitan area networks. In VANETs, mobile nodes are vehicles which are equipped with wireless antennas; and they can communicate with each others by wireless communication on ad-hoc mode or infrastructure mode. Compared with Mobile Ad-Hoc Networks, VANETs have some inherent characteristic, such as high speed, sufficient energy, etc. According to previous research, clustering vehicles into different groups can introduce many advantages for VANETs. However, because a VANET is a high dynamic scenario, it is hard to find a solution to divide vehicles into stable clusters. In this paper, a novel multi-hop clustering scheme is presented to establish stable vehicle groups. To construct multi-hop clusters, a new mobility metric is introduced to represent relative mobility between vehicles in multi-hop distance. Extensive simulation experiments are run using ns2 to demonstrate the performance of our clustering scheme. To test the clustering scheme under different scenarios, both the Manhattan mobility model and the freeway mobility model are used to generate the movement paths for vehicles.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network Protocols

General Terms

Design, Management

Keywords

Clustering, Vehicular Ad-Hoc Networks

*This work is partially supported by NSERC DIVA Network, Canada Research Chairs Program, and ORF/MRI Research Founds.

MobiWac'11, October 31–November 4, 2011, Miami, Florida, USA.

1. INTRODUCTION

In recent years, Vehicular Ad-Hoc Networks (VANETs) have presented wide study because they introduce lots of new applications such as intelligent transportation system, roadside advertisement and online entertainment. In a typical VANET, there are two kinds of wireless nodes, mobile units and roadside units. Mobile units can be any kind of vehicles which are equipped with wireless antennas, such as buses, cars, trucks, etc. Roadside units are some fixed wireless nodes installed on the roadside, and these units can provide wireless connections to the Internet for mobile units. Usually, roadside units are access points which are provided by Internet Service Providers (ISPs). As a result, there are two kinds of wireless communications in VANETs, vehicle to vehicle (V2V) communications and vehicle to infrastructure (V2I) communications. Using V2V communications, vehicles can communicate with other vehicles in ad-hoc mode; and vehicles can transmit emergency messages in this mode. Conversely, using V2I communications, vehicles can access the Internet and communicate with correspondent nodes through the Internet.

To construct VANETs, a lot of wireless transmission technologies can be adopted to be implement in the physical layer, such as IEEE 802.11 [4], WiMax [5], 3G and etc. Considering the deployment cost, the service fee and transmission data rate, IEEE 802.11 is a reasonable technology to provide wireless connection in VANETs. However, due to the limited transmission range of wireless antennas and the high speed of vehicles, the handoff is very frequent in VANETs. To reduce handoff latency and minimize the packet lost during the handoff, we presented a NEMO-based handoff scheme in vehicular networks [14]. In that handoff scheme, vehicles are divided into different clusters and inter-cluster communications are used to receive the available access points before the handoff. Therefore, using multi-hop clusters can extend the coverage range of clusters and gain more advantages comparing with single hop clusters. In our paper, a N-hop cluster is a cluster in which the cluster head node can contact cluster member nodes using maximum N hops. However, to the best of our knowledge, there is no multi-hop clustering scheme designed for VANET; and the multi-hop clustering scheme designed for Mobile Ad-Hoc Networks (MANETs) do not work well in the high speed scenarios. Therefore, we are going to implement a multi-hop clustering scheme for VANETs.

In this paper, we present a multi-hop clustering scheme for VANETs. To the best of our knowledge, this is the first multi-hop clustering scheme for VANETs. To cluster vehicles into different groups, we select the vehicle nodes which have low aggregate mobility as the cluster head nodes. Because we believe that using low aggregate mobility nodes help construct stable vehicle clusters. However, it is hard to model the relative mobility in multi-hop scenarios. In our paper, we use packet transmission delay to represent the logical distance between two vehicle nodes in a VANET. Vehicles broadcast beacon messages periodically, and they use the ratio of packet transmission delay between two successive beacon messages to represent the relative mobility between two vehicle nodes. Therefore, after receiving two beacon messages, the vehicles can calculate the relative mobility between itself and other vehicles. Then, the vehicles can calculate the aggregate mobility metric similar to MOBIC [2]. The vehicles which have lowest aggregate mobility value in their N-hop neighborhood are selected as cluster head nodes and they broadcast cluster information messages in their N-hop neighborhood. Other vehicles will decide to join the cluster when they receive the cluster information messages. After that, the N-hop clusters are generated and the distance between the cluster head nodes and the cluster member nodes are at most N hops.

The remainder of this paper is organized as follows. Preliminary knowledge and related works are presented in Section 2. Detail design of our multi-hop clustering scheme is introduced in Section 3. In Section 4, simulation results and performance evaluation are illustrated. Finally, this paper is concluded in Section 5.

2. RELATED WORK

The clustering scheme has been well studied in wireless ad-hoc networks in recent years [13]. However, considering the characteristic of VANETs, such as high speed, sufficient energy and etc., the clustering schemes proposed for conventional wireless ad-hoc networks are not suitable for VANETs. Therefore, clustering schemes for VANETs should be designed specifically.

The lowest ID clustering algorithm [3] is one of the easiest way to cluster mobile nodes for wireless networks. Using this algorithm, all of the wireless nodes broadcast beacon messages in which the node IDs are encapsulated. Moreover, these nodes IDs are assigned uniquely. The node which has the lowest ID in its neighborhood is selected as the cluster head node; and other nodes are selected as the cluster member nodes. The lowest ID algorithm proposed a basic idea to cluster mobile nodes. First, we need to define a metric to model the property of wireless nodes; and then we can use the metric to group nodes based on some rules. The following clustering schemes are all based on this basic idea. The difference of various clustering scheme is the metrics used for modeling.

Because the lowest ID clustering algorithm did not take into account the mobility, to cluster mobile nodes, a mobility metric is needed to represent the property of mobile nodes. In MOBIC [2], authors proposed a new mobility metric to represent relative mobility between nodes which are in one-hop distance. Using MOBIC, mobile nodes broadcast beacon messages every broadcast interval which is predefined. When a mobile node receives two consecutive beacon messages from its neighbor node, it measures the relative mobility between two nodes as the ratio of the received signal strength of the new beacon message and the received signal strength of the old beacon message. The mobile nodes then calculate the aggregate mobility metric based on the relative mobility. After that, the mobile nodes which have the least aggregate mobility value are selected as the cluster head nodes. Therefore, using MOBIC we can construct clusters in which the maximum distance between the cluster head nodes and other cluster members nodes is one hop.

In [10], authors presented a clustering scheme using affinity propagation for VANETs. Affinity propagation is first proposed to solve data clustering problem and it is demonstrated that this algorithm can generate clusters more efficiently compared with traditional solutions. In [10], the idea of affinity propagation is used to cluster vehicle nodes in a distributed manner. The vehicle nodes exchange messages with their neighbor nodes to transmit availability and responsibility and make the decision based on the availability and responsibility values for constructing clusters. The simulation results demonstrate that the performance of the clustering scheme using affinity propagation is better than MOBIC in terms of stability.

Density Based Clustering (DBC) algorithm is proposed in [6]. Using DBC, connectivity level, link quality and traffic conditions are taken into account completely to cluster vehicle nodes. The mobile network is divided into dense part and sparse part. A node which has links more than a predefined value is considers as in the dense part; otherwise, it is in the sparse part. During the clustering process, link quality is estimated to make re-clustering decision. According to the experiment results, the cluster head change ratio is less than the lowest ID algorithm [3].

In [8], authors presented a direction based clustering algorithm for vehicular networks. Authors assume that each vehicle has a digital map and can calculate the moving path based on the source address and the destination address. The vehicle clusters are formed based on the directions which vehicles take at the intersection of the roads. Therefore, the vehicles which have the same direction will form a cluster. However, this scheme only takes into account the direction; as a result, the cluster will change frequently.

The Distributed and Mobility Adaptive (DMAC) clustering protocol is proposed in [1]. Using DMAC, each node is assigned a weight parameter; and the weight can be computed based on link quality, mobility and etc. The mobile nodes which have the biggest weight are selected as cluster nodes. To adapt DMAC to vehicular environment, a modified DMAC protocol is presented in [12]. The author added the consideration of moving direction when two groups of vehicle meet. If the groups of vehicle are moving in the different direction, the re-clustering process is avoided. Therefore, the algorithm can increase the stability of vehicle clusters.

In [7], the Passive Clustering (PC) scheme is proposed to reduce the messages exchanged for clustering. Using PC, each node maintains its cluster status based on the traffic flows locally; and no cluster control messages are needed to construct clusters. Therefore, the maintenance cost of clusters is decreased. Based on PC, in [11], authors proposed three clustering algorithms which took into account different metrics to construct vehicle clusters. These clustering algorithms are called VPC. Compared with the PC, VPCs can increase performance of packet delivery and reduce the end-to-end delay.

In summary, to generate vehicle clusters, a lot of clustering schemes are proposed considering the inherent characteristic of VANETs. However, all of them can only construct clusters in which the maximum distance between the cluster head node and the cluster member nodes is one hop. Therefore, we want to have some preliminary research work on how to construct multi-hop clusters in vehicular networks.

3. PROPOSED SCHEME

In this section, our multi-hop clustering scheme for VANETs is presented. The basic idea is that we allow the vehicle nodes broadcast beacon messages periodically. Upon receiving two consecutive beacon messages, the vehicle nodes can calculate relative mobility with other vehicle nodes in its N-hop neighborhood. The relative mobility metrics are then used to calculate the aggregate mobility metric; the vehicle nodes which have the lowest aggregate mobility are selected as cluster head nodes. Other vehicle nodes will join the cluster when they receive the messages from cluster head nodes. The notations will be used in our paper is illustrate in Table 1. In addition, the definition of some items is shown as follows.

Table 1: Notations

Notation	Description
$V(i)$	Vehicle i
$Dis(i,j)$	The distance between $V(i)$ and $V(j)$ in hops
$Cluster(m,n)$	A n-hop cluster and the cluster head node of the cluster is $V(m)$
$PktDelay(i,j,n)$	The packet delay of a packet sent from $V(i)$ to $V(j)$ using n hops
$RelM(i,j,n)$	The n-hop relative mobility metric between $V(i)$ and $V(j)$
$AggM(i,N)$	The N-hop aggregate mobility metric of $V(i)$
N	The maximum distance allowed between the cluster head node and the cluster member nodes in hops

If the vehicle node V_i can receive a data packet from the vehicle node V_j in N hops, the vehicle node V_i is the N-hop neighbor of the vehicle node V_j; and the distance between the vehicle node V_i and the vehicle node V_j is N in hops. The property of N-hop neighbors is symmetrical. We assume that the wireless transmission is bi-directional. If the vehicle node V_i can receive a data packet from the vehicle node V_j in N hops, the vehicle node V_j can also receive the data packet from the vehicle node V_i in N hops. Therefore, the vehicle node V_j is also the N-hop neighbor of the vehicle node V_j, if the vehicle node V_i is the N-hop neighbor of the vehicle node V_j.

A N-hop cluster is a cluster in which the cluster head node is the N-hop neighbor of all cluster member nodes. As a result, the maximum distance in hops between the cluster head node and cluster member nodes is N. Moreover, for a N-hop cluster, the diameter in hops should be less than 2N, which means in a N-hop cluster, any two cluster nodes can communicate with each other using less than 2N hops in ad-hoc mode .

The N-hop relative mobility metric is used to represent the relative mobility between two vehicle nodes which are N-hop neighbors in the vehicular network. If absolute value of the N-hop relative mobility metric is low, the relative position of two vehicle nodes is stable.

The N-hop aggregate mobility metric is used to represent the summary relative mobility between the vehicle node and all of other vehicle nodes in its N-hop neighborhood.

3.1 Mobility Metrics

Mobility metrics are used to represent the mobility level of mobile nodes. To calculate relative mobility between two vehicle nodes, a lot of solutions are proposed to represent the metric in the literature, such as relative speed, relative position, ratio of received signal strength from two consecutive packets and etc. Unfortunately, these metrics are not suitable to calculate the N-hop relative mobility for constructing N-hop clusters. Relative speed, which is one of the commonest mobility metrics for mobile nodes, can be used to represent and predict the relative position of mobile nodes. However, it is not good to represent N-hop relative mobility for vehicle nodes, because in the vehicular environment, fading effects caused by obstacles cannot be ignored. Even two vehicle nodes have similar speeds, it is possible that wireless connections could be extremely weak. For relative position, it is possible that two nodes are in the radio range of each other physically and they cannot communicate with each other in one hop because of obstacles. Moreover, the ratio of received signal strength from two consecutive packets proposed in [2] can only be used to represent relative mobility in one hop. Consequently, a new relative mobility metric should be implemented to present the relative mobility relationship between two nodes which are N-hop far.

In this paper, a new mobility metric is proposed to represent the N-hop relative mobility between two vehicle nodes. The ratio of packet deliver delay of two consecutive packets is used to calculate the N-hop relative mobility. Every vehicle node is designed to broadcast a beacon message in its neighborhood for every beacon interval. In the beacon message, the time when the vehicle broadcast the messages is encapsulated. When the neighbor node receives the beacon message, it calculates the packet transmit delay and saves the packet delay in a data structure called neighbor list. If a vehicle node receives two consecutive beacon messages from the same node, it can compute the relative mobility between them. The formula used to compute the relative mobility metric is shown in Equation 1.

$$RelM(i,j,n) = 10log_{10}\frac{PktDelay_{new}(i,j,n)}{PktDelay_{old}(i,j,n)} \quad (1)$$

In the beacon message, the number of maximum hops allowed is also encapsulated. The maximum number of hops is used to control the distance between the cluster head node and the cluster member nodes. Therefore, if we are going to create N-hop clusters, the maximum hop number should be set to N. Besides the maximum hop number, the current hop number is also included in the beacon message. When a neighbor node receives the beacon message, it increases the current hop number by one and checks whether the current hop number is less than the maximum hop number. If the current hop number is less than the maximum hop number, the neighbor node will broadcast the beacon message again. Otherwise, the neighbor node just calculates the packet transmission delay and updates its neighbor list according to the beacon message. In the new beacon message, besides the sending time of previous hops, the time to send the new beacon message is also appended. Therefore, when a vehicle node receives a beacon message, it can calculates the packet delay for all the nodes which the beacon message passed. Moreover, to reduce the beacon message, if the vehicle node finds that it receives or forwards the packet before, the vehicle node drops the packet.

Based on the relative mobility metrics for neighbors in N-hop distance, the vehicle node can compute the aggregate mobility value using Equation 2. The aggregate mobility metric equals the summary of the relative mobility times a weight value for all neighbor nodes in N-hop. The weight metric is used to represent the contribution of different relative mobility to the whole aggregate mobility. Because the vehicle node which can access in less hops is prone to stay in the N-hop neighborhood longer, the weight value of that vehicle node should be assigned a small value. The vehicle nodes which have higher hops have more possibility to change the clusters. After calculating the aggregate mobility metric, vehicle nodes broadcast their aggregate mobility value in the N-hop neighborhood. The vehicle node which has the smallest aggregate mobility value is selected as the cluster head node; and other vehicle nodes work as the cluster member nodes.

$$AggM(i,N) = \sum_{Dis(i,j)\leq N} \|RelM(i,j,n)\| \times \frac{n}{N} \qquad (2)$$

3.2 Multi-hop Clustering

The detail steps of our multi-hop clustering scheme is illustrated in this subsection. The basic idea of our clustering scheme is that the cluster head node is selected based on the mobility metric defined in the previous subsection; and other vehicle nodes will join a cluster in its neighborhood. In general, there are three kinds of states for a vehicle node, CLUSTER_UNDECIDED, CLUSTER_MEMBER and CLUSTER_HEAD. When the a vehicle node joins the vehicle network, it initializes the state status and the state is set to CLUSTER_UNDECIDED. Then the vehicle node can switch its status among these states during the movement. For a vehicle node which is in the undecided state, if it has the lowest aggregate mobility value in its N-hop neighborhood, it will go to the cluster head state; otherwise, it changes to the state CLUSTER_MEMBER. For a cluster member node, if it lose the connection or the cluster is destroyed, it switches its state to CLUSTER_UNDECIDED. Moreover, for a cluster head node, if it meets another cluster head node and the re-clustering process is triggered, it switches its state to CLUSTER_UNDECIDED if it does not have the lowest aggregate mobility value. To control the clustering process, a parameter called beacon interval is predefined to specify the time interval between two consecutive beacon process.

In the first step, every vehicle nodes which want to work in the cluster mode should broadcast a beacon message in its neighborhood to notify its neighbor nodes. The broadcasting process will be repeated every beacon interval. In this beacon message, the sender's address, the transmitted time and the current hop number are encapsulated for calculating the relative mobility metric. When a vehicle node receives a beacon message, it checks the path list in the beacon message to make sure the same beacon packet is not received before. Then it calculates the packet transmission delay between itself and the vehicle nodes appeared in the path list. After that, the vehicle node computes the relative mobility value and updates the neighbor list. Moreover, the vehicle node checks whether the current hop number of the beacon message equals the maximum hop number. If the current hop number is smaller than the maximum hop number, the vehicle node should add itself into the path list of the beacon message and broadcast it again. The process of receiving a beacon message is shown in Algorithm 1. After the vehicle node starts the broadcasting process, it initialize a timer to the predefined value. When the timer expires, the vehicle node terminates the beacon message receiving period.

Algorithm 1 The process of receiving a beacon message

$Nhop$: the current hop number
$V(j)$: the ID of the receiver
$TT(i)$: the transmitted time of $V(i)$
Now: the current time
for all $V(i)$ in the path list of the beacon message **do**
    if $V(i) == V(j)$ **then**
        drop the beacon message;
    end if
end for
for all $V(i)$ is in the path list of the beacon message **do**
    $PktDelay(i,j,n) = Now$ - $TT(i)$;
    if $V(i)$ is in the neighbor list **then**
        calculate the relative mobility metric $RelM(i,j,n)$;
    else
        add $V(i)$ into the neighbor list;
    end if
end for
$Nhop = Nhop + 1$;
if $Nhop < N$ **then**
    $TT(j) = Now$;
    add $V(j)$, $TT(j)$ into the path list of the beacon message;
    broadcast the beacon message;
end if

After the beacon message receiving period, the vehicle node initialize a second timer for receiving aggregate mobility messages and it starts to calculate the aggregate mobility metric using Equation 2. The vehicle node then broadcasts its aggregate mobility value in its neighborhood. The neighbor nodes, which receive the aggregate mobility message, update its neighbor list and save the aggregate mobility value. For the aggregate mobility message, a parameter called current hop number is also encapsulated to control the forwarding process. When the vehicle node receives the aggregate mobility message, the current hop number is increased by one; and the current hop number is compared with the maximum allowed hop number predefined. If the current hop number is less than the maximum allowed hop number, the vehicle node add its own aggregate mobility value into the aggregate mobility message and broadcasts the message in its neighborhood again. After the timer expiring, the vehicle node compares its aggregate mobility value with other vehicle nodes' aggregate mobility value in its neighbor list. If the vehicle node has the smallest value, it changes its state to cluster head node and broadcasts vehicle cluster information message in N hops. Otherwise, the vehicle node will be a cluster member node and listens to the cluster information message. The vehicle node will join a cluster if it hears the cluster information message from the cluster head node of that cluster. A special case is that a vehicle node receives multiple cluster information messages. In that case, the vehicle node selects the cluster head node which is the closest one in hops, and joins the cluster led by that cluster head node. If several cluster head nodes have the same hops to the vehicle node, the vehicle node joins the cluster led by the cluster head node which has the lowest relative mobility value. The process of selecting the cluster is shown in Algorithm 2

Algorithm 2 The process of selecting the cluster

$SNhop$: the smallest hop distance between the vehicle node and a cluster head node
$V(j)$: the ID of the vehicle
$V(c)$: the cluster head node candidate
$SNhop = N$
for all $V(i)$ in the neighbor list **do**
  if $V(i)$ is a cluster head node **then**
    if $SNhop > Dis(i,j)$ **then**
      $SNhop = Dis(i,j)$;
      $V(c) = V(i)$
    else if $SNhop == Dis(i,j)$ AND $RelM(i,j) < RelM(c,j)$ **then**
      $V(c) = V(i)$
    end if
  end if
end for
$V(j)$ joins the cluster which is led by $V(c)$;

Using our clustering scheme, at the beginning of the process, the distance between two cluster head nodes should be more than N in hops. However, after moving, it is possible that two cluster head node will meet each other during the moving path. When two cluster head nodes can contact with each other using less than N hops. The re-clustering process will be triggered. To reduce the re-clustering cost, the re-clustering process is deferred. Instead of starting the re-clustering process immediately, the re-clustering process is started when the two cluster head nodes are in the contact range for several broadcast intervals. Therefore, the time of re-clustering is reduced and the cluster head duration time is increased.

4. SIMULATION RESULTS

In this section, the simulation results and performance evaluation of our multi-hop clustering scheme is presented. To simulate our multi-hop clustering scheme, the Network Simulator - ns2 (Release 2.34) [9] is used to implement the clustering protocol. To generate the movement path file, two different mobility models are used to evaluate our clustering scheme extensively: the freeway mobility model and the Manhattan mobility model [15]. For the Manhattan mobility model, the probability of moving forward is set to 0.5, and the probability of turning left or right is set to 0.25 separately. The other general simulation parameters are illustrated in Table 2. For each test, the simulation runs 600 seconds; however, the clustering process starts at 300 seconds. To evaluate our multi-hop clustering protocol, three performance metrics are selected to demonstrate the performance: cluster head duration, cluster member duration and cluster head change number. These performance metrics can demonstrate the stability of our clustering scheme.

4.1 Cluster head duration

The cluster head duration is the time interval from when the vehicle node becomes the cluster head node to when the vehicle node gives up the cluster head role. The average cluster head duration of our scheme under two mobility scenarios are shown in Figure 1 and Figure 2 separately. In our simulation tests, the maximum number of hops in the cluster is changed to find how the maximum hops effectthe performance. Three different values are used in the simulation, N = 2, 3 and 5. Figure 1 illustrates the average cluster head duration when we used Manhattan mobility model to generate moving path files. We did the tests using different maximum velocity. According to Figure 1, the average cluster head duration will decrease when the maximum velocity of vehicles increase. This is because when the vehicles move faster, the topology of the vehicle network is more dynamic. When the maximum speed changes from 10 m/s to 35 m/s, the cluster head duration is reduced about 20%. Moreover, the parameter of the maximum hops used to cluster vehicles will also effect the performance significantly. If we define a large value for N, the cluster head duration is larger than the one when we use a small value for N. This is because the value of the maximum hops determines the distance between two cluster head nodes. If a large maximum hops number is used, the distance between two cluster head nodes should be far. Therefore, the time interval that two cluster head nodes spent to meet each other is long, and the time between two re-clustering processes is also long. As a result, the cluster head duration is long.

The average cluster head duration of scenarios in which the freeway mobility model is used is shown in Figure 2. Similar to the results of the Manhattan mobility model, the average cluster head duration is decreased when the maximum velocity of the vehicles is increased; and when the value of maximum hops increases, the average cluster head duration also increases. Comparing with the results of two mobility models, we can see that the average cluster head duration using freeway mobility model is larger than the value using the Manhattan mobility model. This is because using freeway mobility model, the vehicles have stronger connections with each other and the mobility is lower than the Manhattan mobility model.

4.2 Cluster member duration

The average cluster member duration of our scheme under two mobility scenarios are shown in Figure 3 and Figure 4 separately. The cluster member duration is the time interval from the time when a vehicle node joins a specified cluster to the time when the vehicle node leaves the cluster. The cluster member duration also demonstrate the stability of the clusters. Similar to the average cluster head dura-

Table 2: Simulation parameters

Parameters	Value
Simulation time	600 s
Area range	1000 m * 1000 m
Maximum velocity	10 - 35 m/s
Number of vehicles	100
Transmission range	120 m
Transmission rate	54 Mbps
Propagation model	Two-ray ground model

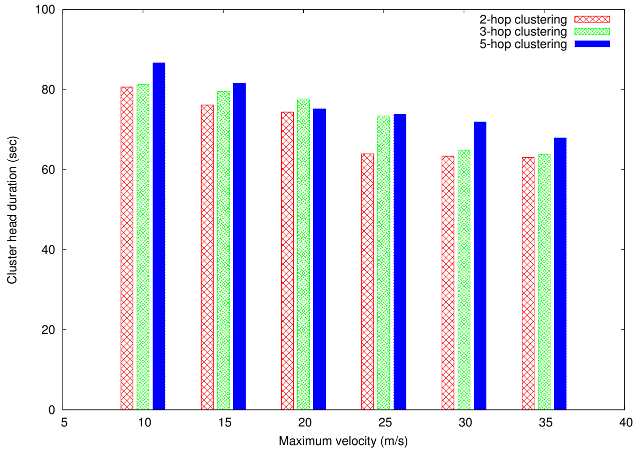

Figure 1: Average cluster head duration using Manhattan model

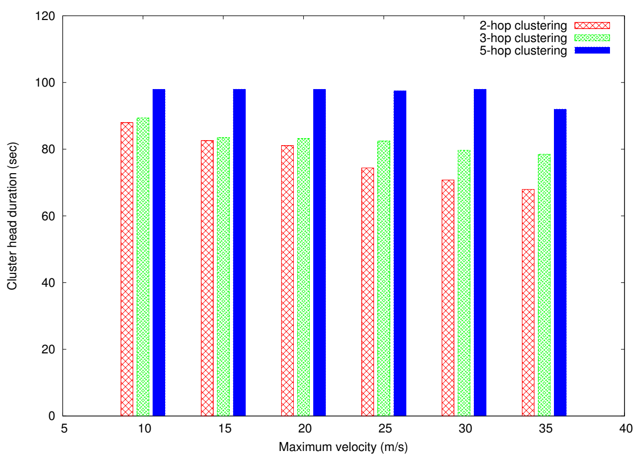

Figure 2: Average cluster head duration using the freeway model

tion, we use different maximum speed and maximum hops to show the relation between different parameters and the cluster member duration. In Figure 3, the average cluster member duration under the scenario which uses the Manhattan mobility model is illustrated. According to Figure 3, we can conclude that the average cluster member duration decreases when the maximum velocity of the vehicle nodes increases and the average cluster member duration increases when the maximum hops increases. When the maximum speed increases, the average vehicle speed will also increase. The vehicles which have high speed will have higher mobility than the vehicles which have lower speed. As a result, it is more possible for vehicles to change their clusters when the vehicles have high speed. The cluster member duration increases when the maximum hops increases is because that it is more possible for the cluster member vehicles to remain connections with the current cluster head nodes when we use a large maximum hop number. If the cluster member nodes can connect to their cluster head nodes, they do not need to change their clusters. Therefore, the cluster member duration increases when the maximum hop number increases.

Figure 4 illustrates the average cluster member duration

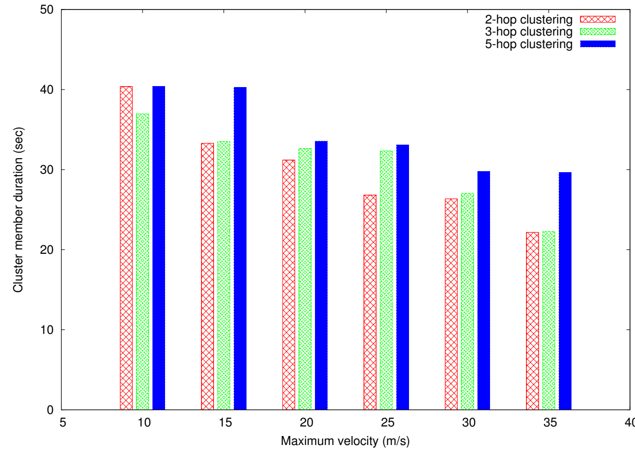

Figure 3: Average cluster member duration using Manhattan model

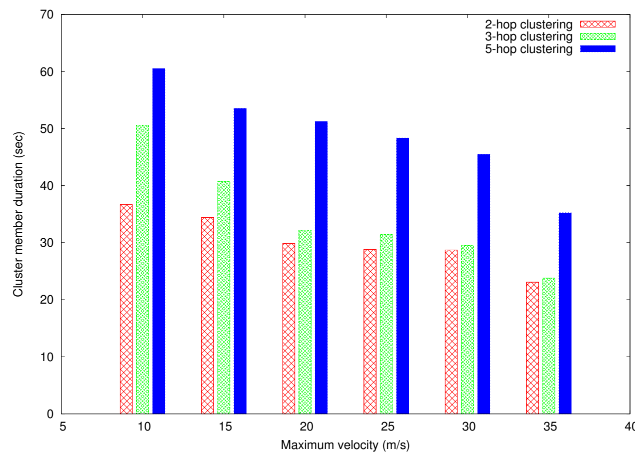

Figure 4: Average cluster member duration using the freeway model

using the freeway mobility model. It shows that the average cluster member duration has the same trend as the results using Manhattan mobility model. The cluster member duration increases when the maximum velocity of vehicles decreases. In the meantime, when the maximum hop number increases, the cluster member duration time also increases. Moreover, the simulation results show that the performance using the freeway mobility model is better than the result using Manhattan mobility model. The reason is that when we use the movement paths which are generated using the freeway mobility model, the vehicles only go forward and there is no turning action. The mobility using the freeway mobility model is lower than the mobility using the Manhattan mobility model. Therefore, the average cluster member duration using the freeway mobility model is higher.

4.3 Cluster head change number

Cluster head change number is the number of the cluster head change during one simulation experiment. The cluster head change number increases when a vehicle becomes the cluster head node. The average cluster head change number of our scheme under two mobility scenarios are shown in

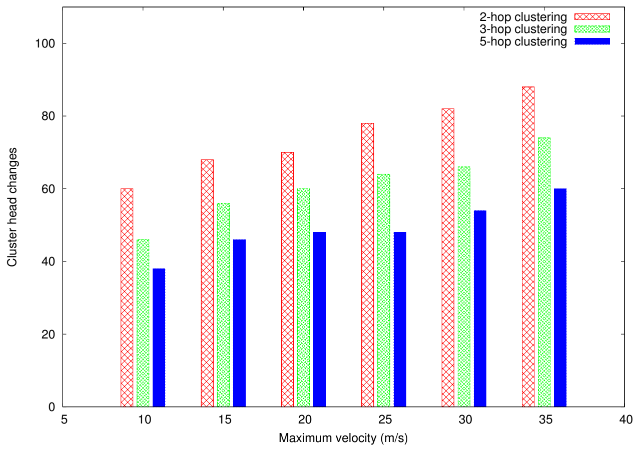

Figure 6: Average cluster head changes using the freeway model

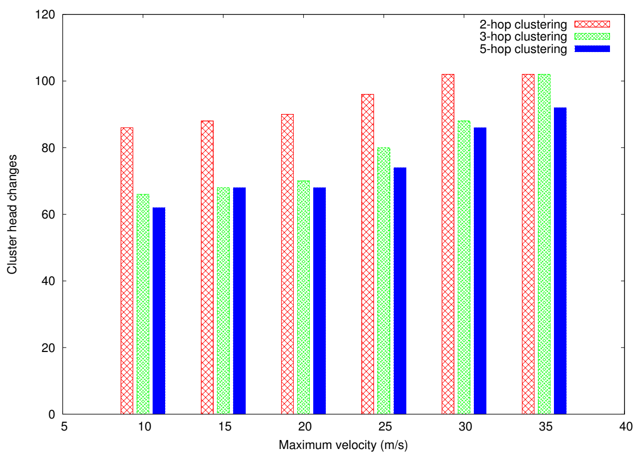

Figure 5: Average cluster head changes using Manhattan model

Figure 5 and Figure 6 separately. The cluster head change number can also demonstrate the stability of a clustering algorithm. When the vehicles have high mobility, a vehicle node will switch from the cluster member node to the cluster head node or from the cluster head node to cluster member node frequently. Therefore, in Figure 5 and Figure 6, we can see that the cluster head change number increases when the maximum velocity of vehicles increases, and it decreases when the maximum hop number increases. When the maximum velocity increases, the probability of two cluster head nodes meet each other is becoming higher; therefore, one of the cluster head nodes will become a cluster member node and the cluster will be removed. Some of the cluster member nodes in that group will join other groups, and some of the cluster member nodes will select a new cluster head node and construct a new group. Consequently, the cluster head change number increases. When we set a large number for the maximum hop number, the cluster nodes will have strong connections with each other and the cluster will be stabler. Therefore, the cluster head change number is decreased when the maximum hop number increases. Comparing the results of two mobility mobility models, the average cluster head change number using the freeway mobility model is smaller than the number using the Manhattan model. The reason is that the mobility of vehicles which move according to the freeway mobility model is less than the mobility of the vehicles using the Manhattan mobility model.

5. CONCLUSION

In vehicle networks, constructing clusters can improve the performance for wireless communications, such as data forwarding, handoff, etc. The question of how to construct stable clusters for reducing cluster head changes and increasing cluster member duration is very important in VANETs. A lot of solutions have been presented in the literature; however, to the best of our knowledge, there is no solution to construct multi-hop clusters for VANETs. In this paper, a new mobility metric to represent N-hop mobility for vehicular networks is proposed. Based on this mobility metric, a multi-hop clustering scheme is presented. Simulation results demonstrate that our scheme can cluster vehicle nodes efficiently. To further improve our cluster scheme, the security problem will be taken into account.

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