

# Traffic Model for Clustering Algorithms in Vehicular Ad-Hoc Networks

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**Abstract**—Inter-vehicle communication by means of wireless Ad Hoc networking has the potential to improve traffic safety and comfort tremendously. Therefore, the application of Vehicular Ad Hoc Networks (VANETs) in the service of Intelligent Transportation Systems (ITS) has been highly focused in recent years. Derived from the successful outcome of a cluster-based framework in Mobile Ad Hoc Networks (MANETs), we apply this network topology to VANETs. Unfortunately, previous studies lack realistic modeling of vehicle mobility and evaluation of clustering performance so they may not correlate well with performance in a real deployment. Hence, in this paper, we propose a realistic micro-simulation model with the hope of contributing to clustering research in VANETs, and demonstrate how clustering algorithms work on it.

## I. INTRODUCTION

Mobile ad-hoc-networks (MANETs) have been investigated and applied to a lot of areas. With the burgeoning need for the service of Intelligent Transportation Systems (ITS), communication between vehicles is considered a prime area where Vehicular ad-hoc-networks (VANETs) are likely to be deployed in the near future. The U.S. Federal Communications Commission (FCC) has recently allocated the 5.85-5.925 GHz portion of the spectrum to inter-vehicle communication (IVC) and vehicle-to-roadside communication (VRC) under the umbrella of dedicated short-range communications (DSRC [15]). This has fuelled significant interest in applications of DSRC to driver-vehicle safety applications, infotainment, and mobile Internet services for passengers.

Vehicles in a VANET environment move within the constraints of traffic flow while communicating with each other via wireless links. Ad hoc networks use less specialized hardware for infrastructure support and leave the burden of network stability on the individual nodes within the network. Without routers, or other dedicated communication hardware, a possible method to optimize communication within the network is to develop a hierarchical clustering system within the network. To support the dynamic nature of the VANET environment, the clustering must be periodically

updated to reflect topological changes and vehicle movements. Clustering within the network must be very fast to minimize time lost to clustering [1].

A significant amount of research [4,5,6] focuses on optimal methods for clustering nodes in MANETs. VANETs, however, pose new challenges in cluster head selection and network stability. First, nodes or vehicles must follow constraints set in place by the real road network topology. Second, vehicle movements follow well-understood traffic movement patterns. Third, vehicles generally travel in a single direction and are constrained to travel within a two-dimensional movement. Given these movement restrictions it is possible to approach clustering more intelligently and possibly discover a better clustering methodology for VANET environments.

Many simulation tools such as ns-2 [14] have been designed for MANET implementations. These tools, however, fail to adequately model the needs of a VANET network. Therefore, for the purpose of this study, a micro-simulation tool [11] is specially modified to perform randomized vehicle-based clustering under traffic constraints. In the model presented in this paper, since we will make it public, users can easily implement and test their own clustering algorithms in terms of stability right now. This model also allows users to change simulation scenarios and traffic parameters. In the future, more features, such as routing, will be added on.

The rest of the paper is organized as follows: in Section 2, a summary of background knowledge and related work are presented. We introduce the characteristics of our simulation model in Section 3. In Section 4 we discuss the simulation results from our case study. Section 5 concludes the paper and discusses some directions of future research.

## II. BACKGROUNDS AND RELATED WORK

### A. Clustering in MANETs

Clustering algorithms are applied in communication networks to organize all nodes into groups and to obtain

a hierarchical network organization. Figure 1 provides an example of the organization of twelve nodes into three clusters. The basic communication capability between the twelve nodes is outlined as connections between the lower tier of the hierarchy. In the upper tier, the three cluster head nodes are displayed with connections between them representing the possible message paths under the cluster-constrained network [2].

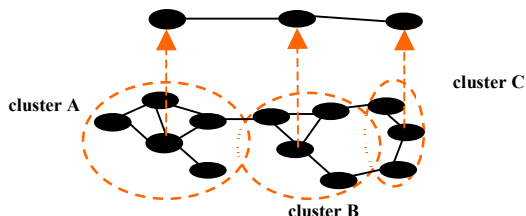


Figure 1. Clustering Within a 12-node MANET Environment

Under this architecture each cluster head aggregates local member topology and acts as a relay point for communication between its members and members of other clusters. This reduces the messages exchanged between individual network nodes and the overhead of information stored within those nodes [3].

Cluster formation in MANETs has attracted considerable attention in recent Times [4,5,6]. Several algorithms have been proposed, such as Lowest-ID algorithm [7,8,9] and Highest-Degree [7] algorithm. In Lowest-ID, if a node hears from a cluster head with a lower ID than itself, it resigns and uses that node as a cluster head instead. In Highest-Degree, it uses the degree of the nodes, which is the number of neighbors within its predefined transmission range, instead of ID to elect cluster heads. The performance of these two algorithms was shown in [5,7]. The two algorithms presented in this paper are superior to other algorithms in terms of their constant time complexity and good scalability.

Our current model only supports clustering algorithms with one hop in communication, and it is very convenient for users to have a multiple hop implementation. The one hop method simplifies the overall communication, clustering strategy and reduces the bookkeeping necessary to maintain the clusters.

### B. Micro-Simulation Model

Traffic micro-simulation models [11,17] are computer models in which the movements of individual vehicles traveling around road networks are determined by using simple car following, lane changing and gap acceptance rules. They are becoming increasingly

popular for the evaluation and development of road traffic management and control systems.

More than fifty traffic micro-simulation models [16] were developed around the world, yet many of them were designed for specific purposes. There exists general-purpose tools, however, they are mostly proprietary and lack friendly API interfaces. Hence we need to find tools relevant to clustering research.

## III. MODEL OVERVIEW AND KEY FEATURES

In this research, we modified an open-source micro-simulation tool called Traffic Simulation 3.0 [12] to our clustering-oriented simulator. It applied the Intelligent-Driver Model (IDM) [13] to simulate the longitudinal dynamics, and Minimizing Overall Braking decelerations Induced by Lane changes (MOBIL) [14] as lane change model.

In this section, two types of clustering functions and other key features will be discussed.

### A. Basic Function

This simulation model focused on providing the most frequently used functions (see Table 1) according to clustering formation. It also provides traffic statistic functions which are unique to vehicular networks (see Table 1). As a result, this model allows users to assemble their clustering algorithms by making use of those basic functions.

TABLE I. TWO TYPES OF FUNCTIONS IN THIS MODEL

Functions	Name
Frequently-Used	Transmission Range, Velocity Vehicle ID, Degree, Position, Cluster head Duration Neighbour Position, Velocity ...
Traffic Statistics	Acceleration, Average Velocity within a period time Average Acceleration of all neighbours Average Position of all neighbours ...

### B. Utility Function

This function makes it possible for each vehicle to implement some form of utility analysis of each proximally located possible cluster head. Periodically, each vehicle will broadcast general network information such as ID and current degree as well as vehicle-specific traffic statistics. Upon receipt of this information, each vehicle chooses a cluster head by evaluating the utility function of each potential head. The node with the maximal utility value is selected as the cluster head. The belief is that these traffic-specific utility functions will be better predictors of the common traffic situations that lead to cluster dissociation. Here is an example of utility function:

**Closest Position to Average (CPA):** A vehicle attempts to choose as its cluster head in order of the absolute difference of candidate's position to the average position of all proximal vehicles.

These detailed steps outline the procedure for implementation of the utility function:

1. Each vehicle determines the vehicles within range by polling the local broadcast region and tracking the candidate cluster head set  $C$ . All vehicles within broadcast range are considered candidate cluster heads.

2. Using candidate set  $C$  and the state information received by broadcast; each candidate is evaluated using CPA function.

3. The cluster head is chosen in decreasing order of CPA value. The petition for cluster membership is broadcast to the chosen vehicle. If the chosen vehicle denies the request, then the vehicle with the next highest utility is selected and this step repeated.

**Case Study:**

Motivated by our previous work [18], we implemented a **Weighted Utility Function (WUF)** as a case study in this paper. This implementation effectively combines several parameters with certain weighting factors chosen according to the model needs. The goal is to improve upon the initial clustering logic to obtain better stability over the simulation time. Below is the detail description of **WUF**:

$$Utility = W_1 \cdot ID + W_2 \cdot \Delta D + W_3 \cdot SD + W_4 \cdot AVT$$

$$\sum W_i = 1$$

1. Use the *Degree Function* to get the degree difference  $\Delta D$  of each vehicle within some time period  $T$ . This reflects the neighboring stability of this vehicle.

2. For every vehicle, use the *Distance Function* to compute the sum of distance  $SD$  with its neighbors.

3. Use the *Average Velocity Function* to compute  $AVT$  for every vehicle within some time period  $T$ . This gives a measure of mobility.

4. Calculate the utility for each vehicle, and choose that vehicle with the smallest utility as the cluster head.

The first component  $ID$  is measured as the stability effect of original Lowest-ID algorithm. The second component,  $\Delta D$ , contributes towards the combined utility because it is always desirable for a cluster head to have less neighboring changes. The motivation of  $SD$  is mainly because a cluster centroid is the best position to manage a cluster, and it will

reduce the transmission delay time as well as keep a cluster relatively stable. Therefore, the closer a vehicle to its centroid, the better a cluster head it will be. The last component is due to mobility of vehicles. As discussed previously, a vehicle with relatively stable mobility to its neighbors is always a better choice for a head.

Many utility functions could occur as the result of combination of basic functions and this utility function is one of them. Users are allowed to choose any desired parameters of this model as their utility function components to design new clustering algorithms. In the later part of this paper, we will show the simulation results of this case study.

**C. Scenarios and Traffic Parameters**

As known in MANETs [4,5], different simulation scenarios and traffic parameters may influence the same clustering algorithm result greatly. In this regard, we have implemented all above functions under six different scenarios in this micro-simulation model. Users could test their algorithms under different scenarios and parameters.

TABLE II. SIX SCENARIOS IN THIS MODEL

Scenarios	Descriptions
Ring Road	Two-lane traffic in a closed system
On-Ramp (Figure 2)	On-ramp acts as a stationary bottleneck to a traffic breakdown on the main road
Lane Closing and Speed Limit	An open system with a lane closing and speed limit
Uphill Grade	Shows the uphill gradients effects
Traffic Lights	Shows the traffic light effects on roadside
Lane Change	Shows the effect on a ring road with obstacles on both lanes, and vehicles are forced to perform four lane changes

TABLE III. MAJOR PARAMETERS IN THIS MODEL

Parameters	Descriptions
Main Inflow	The volume of main traffic flow pouring into the system
Ramp Inflow	The volume of traffic flow through ramp pouring into the system
Average Density	The total number of vehicles within the closed ring-road system
Politeness Factor	The waiting patience degree of moving from ramp onto the main road

Although some other parameters are available, these are the major factors that influence simulation results.

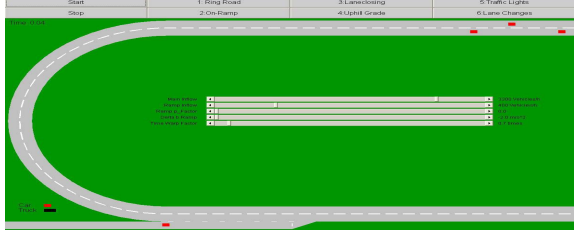


Figure 2. Screenshot of On-Ramp Scenario

#### D. Other Features and Simulation Metrics

In terms of clustering visualization, the graphical display of this model was modified to display vehicle clusters using contrasting colors. In addition to display changes, we implemented the model with the periodic state logging (bookkeeping vehicular related information, e.g. Position, Degree etc) in favor of simulation results analysis. It provided the basis for the simulation result analysis and algorithm comparison.

To measure the system performance, two metrics were identified: (i) the average cluster head change per step and (ii) the average cluster size. Metric (ii) alone does not accurately depict system performance, so the relative measurement (ii)/(i) was introduced to provide a reasonable comparison metric between the analyzed algorithms. A method is considered relatively better if it has either better stability using metric (i) or larger average cluster size.

Why two metrics? Due to the dynamic nature of traffic flow, the member vehicles as well the cluster heads tend to move in semi-related motion throughout the roadway. This motion destabilizes the network clusters and warrants periodic cluster reformation. Re-clustering may result in transition of nodes from one cluster to another, split of a cluster into more than one cluster, or convergence of multiple clusters into a single larger cluster. The frequency of cluster formation and cluster change is thus an important consideration in algorithm evaluation. Equally important is the size of each cluster. Resource and relay algorithm performance considerations may limit the manageable size a cluster head's cluster.

### IV. RESULTS DISCUSSION

The simulation results represent the performance of Lowest-ID, Highest-Degree and WUF algorithm across various wireless transmission range values (0-300 meters) and maximum vehicle speed (40-140 kilometers/hour) with a fixed maximum cluster degree  $M = 50$  vehicles. The values use for simulation were  $W_1 = 0.6$ ,  $W_2 = 0.2$ ,  $W_3 = 0.1$  and  $W_4 = 0.1$  (this settings had nice performance under current system). Note that these values are arbitrary and should be adjusted according to the model requirement. In

addition, all simulations are tested under the On-Ramp scenario and the simulation time duration was held constant across all tests. To minimize traffic flow variability between simulations and enable repeatable test results, the randomized features of the model were seeded with the same value at each simulation run. In the future, we plan to test and compare latest algorithms instead of just those two.

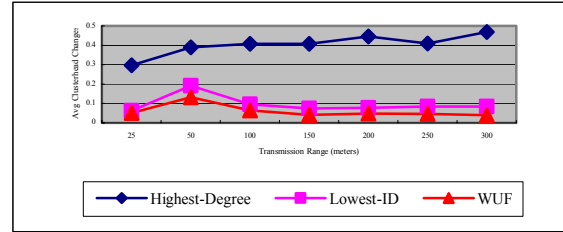


Figure 3. Cluster Changes vs. Range

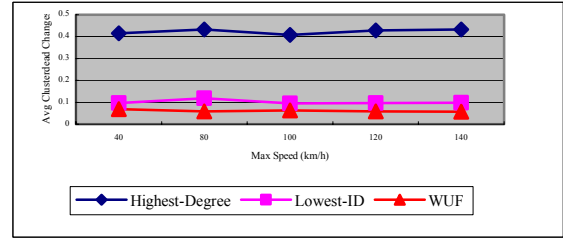


Figure 4. Cluster Change vs. Speed Limit

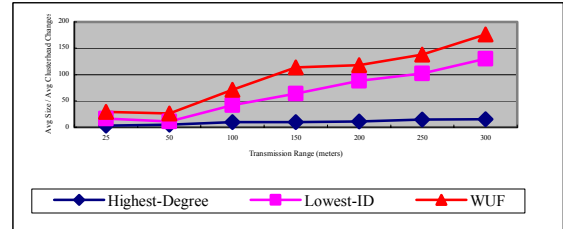


Figure 5. Clustering Ratio vs. Range

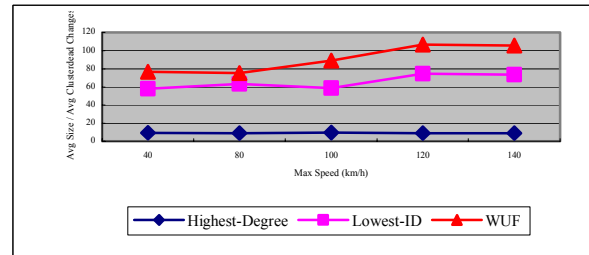


Figure 6. Clustering Ratio vs. Speed Limit

Figure 3 summarizes the variation of the average number of clusters in unit time with respect to the transmission range. It illustrates the performance of the two algorithms for a reasonably standard traffic flow environment with a fixed maximum speed of 100km/h. In the figure, the maximum clusters change value is 1.0 indicating that a vehicle will change its head every unit time, therefore the lower the curve, the more stable the algorithm. Notably, the WUF clustering enabled the most stable clusters. The WUF logic not only has an effect on an already good-performing algorithm as Lowest-ID, but did help reduce the initial peak values seen with the simple method at a 50m range. In addition, the sudden drop around 50m is due to the network disconnectivity.

Figure 4 shows the effect of varying the maximum speed on the average number of cluster head changes with a fixed transmission range of 150m. Algorithm performance is consistent with those of Figure 3. Speed limits are useful only in heavy-traffic situations [12]. Figure 5 displays the performance of all algorithms over various transmission ranges. Higher curves indicate better performance. Figure 6 shows the overall performance across various speed limits. Particularly, WUF has shown clearly a nice performance gain in Figure 5 and 6 since it has a good cluster size for reducing communication overhead.

## V. CONCLUSION AND FUTURE WORKS

From the above discussion, this analysis highlights the performance improvement of the WUF algorithm to the well-known Lowest-ID and Highest-Degree algorithms for the constrained MANET environment provides by VANETs. The study maintained stable performance without any major overhead. Furthermore, this paper presents a simulation model for testing clustering algorithms under VENET environments. This model provides basic clustering functions as well as some traffic-specific statistics. It is capable of implementing a utility function by combining some basic functions. Also, it takes into consideration the simulation scenarios and traffic parameters.

The results of this research provide an initial approach and testbed model to analyzing parameterized VANET dynamics from a traffic micro-simulation

perspective. Future work will be focused on exploring more basic functions and metrics, especially with respect to routing, and developing a friendly user interface. Evaluation of cluster-based routing algorithms under VENET environments would be very important as well. Furthermore, we will also study the use of optimization algorithms such as simulated annealing and genetic algorithms for use in determining the best utility function weights.

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