EE299 Project Course

Vehicular Ad Hoc Networks (VANET)

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# Routing in Sparse Vehicular Ad Hoc Wireless Networks

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## Introduction of Routing in Sparse VANET

This paper focuses on a specific case of a Vehicular Ad Hoc Network (VANET) where a fully connected network infrastructure may not be present. In a real world setting, the availability of relay towers or other vehicles capable of relaying information may not be in range or not present at all. In the article “Routing in Sparse Vehicular Ad Hoc Wireless Networks”, the assumption is that a communication network will be fragmented and sparse at times and the models and frameworks developed will take into account the varying vehicle densities and market penetration of a given network system. By using this assumption the models developed to describe network behavior given varying vehicular densities are proven to be acceptably accurate by comparing the analytical results against multiple Monte Carlo simulations as well as data collected from empirical studies of real world traffic scenarios.

## Describe Problem

Much research is devoted to developing routing algorithms and protocols for communication between vehicles in a dense network setting or resolving the issue of broadcast storms. Although this is a valid scenario it does not include scenarios where the connectivity of a network may not be reliable such as in rural areas or late night traffic situations where it may not be possible to maintain a connected network. The research set forth will instead focus on the situation where a consistent connected network is not always feasible and develop models that incorporate network fragmentation into the solution.

Focusing on the fact that any particular VANET will at times experience network discontinuity three key questions must be answered:

1. What are the consequences when trying to relay safety messages to other vehicles when the network is constantly disconnected?
2. In a disconnected VANET what are the key characteristics to observe and what are the adverse effects on performance in the network?
3. What is the solution to a disconnected VANET if any? And if there is not a viable solution to this problem how can the affects of network fragmentation become minimized?

In this paper, not only will it highlight the reality of network fragmentation in real world settings, it will also introduce a possible solution to the disconnected network issue. The solution proposed, “Stored-carry-forward” mechanism, will prove to be viable through analytical and simulation results, as well as comparing with empirical data collected by the Berkeley Highway Laboratory (BHL).

The BHL research is vital to proposed model because it realistically influences important parameters of the model such as inter-arrival time and inter-vehicle spacing between vehicles. For example through the empirical studies the results showed that inter-vehicle spacing follows an exponential distribution when the traffic volume is below 1000 vehicles/hour. Furthermore, with the assumption that all vehicles possess the technology of wireless communications, the network still experienced network discontinuity of up to 35% during hours of low traffic volume.

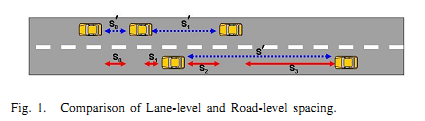
## Proposed Model

The foundation of this model is based on a well known model, the Car following model. This model assumes a single-lane scenario with any type of traffic conditions. Another assumption is that drivers drive safely and that drivers’ deceleration factors are taken into consideration. The model is shown below:

|  |  |
| --- | --- |
|  | * S’ - headway spacing between rear bumper to rear bumper * L - effective vehicle length in meters * - driver reaction time in seconds * V - vehicle sped in meters/second * - reciprocal of twice the max average deceleration of a following vehicle (ie approximately 0.075 ) |

To simplify the model, with the “good-driver” assumption. This assumes that every driver will have a similar deceleration factor which simplifies the above the original equation to:

The car following model describes adjacent vehicles that are travelling in the same lane. From a network perspective, it is irrelevant whether the following car is in the same lane or next because our focus is network connectivity, which depends more on the distance away from a particular vehicle regardless of position. Because of this the model is expanded to represent a multi-lane system. Below we observe the distinction between a single-lane (blue arrows) and multi-lane (red-arrows) model. The arrows in blue are only associated with vehicles directly in the same lane where as the red arrows are associated with the next closest vehicle in proximity.



Another adjustment that needs to be made is with (the driver reaction time). Through raw data collection during moderate to light traffic, was as large as 50-100 seconds. This is unrealistically high as a representation for driver reaction time, so instead will replace as the inter-arrival time of vehicles. The final adjustment is the minimum spacing L. Because of the multi-lane configuration we expand L to to represent the minimum distance between any 2 vehicles regardless if they are in the same lane (red arrows). The new model then becomes:

|  |  |
| --- | --- |
|  | * – road level inter-vehicle spacing * - minimum spacing between any two adjacent vehicles * - inter-arrival time of vehicles on any lane from fix observation point * V - vehicle sped in meters/second |

This model is now capable of characterizing traffic conditions in both heavy and light traffic situations. The next step to making this model more tangible is to correctly or approximately calculate the inter-arrival time and vehicle speeds. We can leverage the data collected by BHL to approximate these two parameters to give realistic values for in different traffic situations.

## Empirical Research Results

The basis of the proposed research solution is based heavily on empirical data collected in a real world environment. The data was collected by BHL on the eastbound I-80 five lane freeway on June 27, 2006 for a time span of 24-hours with a recording frequency of 60 recordings per second. Given the measurements it is possible to approximate the inter-arrival times and average vehicle speeds for different traffic conditions. To better represent vehicular traffic conditions three different time periods are used to distinctly represent three varying conditions. 1am-3am models sparse traffic conditions where vehicles are traveling at higher speeds, 10am-12pm represents moderate traffic conditions and average speed, and 3pm-5pm will be the case of rush hour where vehicles are tightly packed traveling at low speeds. Figure 2 and 3 are the results charting the vehicles/hour (traffic density) and speed of vehicles against the time of day.



From the data in figure 2 and 3 the inter-arrival time and the average vehicle speed V can be approximated for the three different vehicle density scenarios. Graphing the results of the extrapolation we can see that the inter-arrival time can be closely approximated by an exponential distribution during the early morning period while the speed of vehicles resembles a normal distribution. Because this research is centered on the notion that a network will inevitably be fragmented we will emphasize the results between 1am-3am which most closely represents a network that will display sporadic connective behavior. Figure 4 shows the Probability Density Functions (PDF) of both the inter-arrival times and vehicle speeds. Particularly figure 4(a) will be of high value in aiding to determine an appropriate inter-arrival time β.



## Solution

First we must define what is meant by disconnection from the network. We will consider two vehicles to be network disconnected if their distance is greater than 250 meters. Given this constraint we need to develop an expression for the inter-arrival time β . The rate of measuring the inter-arrival time was 60 recordings per second so we can characterize the parameter to fit the collected data of volume per hour. From figure 4(a) for the time period of 1-3am (the scenario that we are concerned with) we observed earlier that it fits an exponential distribution so we can characterize the PDF of β by (Note: the general form of an exponential distribution is ). Earlier we derived the inter-vehicle spacing equation . Given the empirical data collected a reasonable approximation for the inter-vehicle spacing is simply the product of the inter-vehicle arrival time and vehicle speeds . Having a PDF for we can then calculate the cumulative density function (CDF) for the inter-vehicle spacing. Figure 5 shows the empirical results for the PDF and CDF of the inter-vehicle spacing.

65% chance of being in range (R ≤ 250 meters)



First looking at figure 5(b), we can see that the PDF of S for the time frame of 1-3am shows that the inter-vehicle spacing varied from 0 – 1000km. By taking the integration of the PDF in which the inter-vehicle spacing is less than R=250m, then we can gauge the frequency of being disconnected in the network. By solving and plotting the CDF we are able to derive figure 5(b). For R=250m we can visually see that there is about a 65% chance of being within range of the communication network, meaning we have a 35% chance of being disconnected network. However, in reality the probability of being disconnected will be higher because this result assumes that every vehicle possesses the equipment to be connected in the network.

In a similar vein we can represent the Inter-vehicle spacing with a similar exponential distribution. First we define the parameter . Now we can then define the Inter-vehicle spacing to be . Later on we will analyze how similar the two derived PDF are with the empirical findings for the time frame 1-3am, which suits the basis of our study of a randomly disjointed network.

### Characteristics of Disconnected Vehicular Ad Hoc Network

As stated before the chosen time frame of study is between 1-3am because it represents the case when a VANET is periodically disjointed. To properly model this scenario many factors have to be taken into consideration. Specifically the goal is to develop a model to also characterize the “probability of being the last vehicle in the cluster, average intra-cluster spacing, average inter-cluster spacing, average cluster size, and average cluster length [1].”

Going back to the minimum distance for network connection, R≤250m, a cluster is defined as any adjacent vehicles that are within the range of R. Studying cluster characteristics will shed light on a disconnected VANET as well as aid in developing the framework to model such a VANET.

#### Probability of Being the Last Vehicle in a Cluster

We want to know the probability of being the last vehicle in a cluster because this should be the last vehicle to disseminate a message across a cluster boundary to optimize the end-to-end latency. We can make use of the inter-vehicle spacing PDF by calculating the probability of a distance greater than R=250m.

Inter-Vehicle Spacing PDF

Now we can calculate the probability of being the last vehicle in a cluster, in other words the probability of having an Inter-Vehicle spacing greater than R=250m.

#### Average Intra-cluster Spacing

The Intra-Cluster spacing is described as the vehicle spacing within a given cluster. Vehicles within the proximity of R≤250 are considered to be in the same cluster, thus the PDF of the Intra-Cluster spacing can be defined as follows:

Taking the expectation of we get:

#### Average Inter-Cluster Spacing

The Inter-Cluster spacing is the shortest distance between two adjacent clusters. This is most easily visualized as the distance between the last vehicles in a cluster with the first vehicle in a separate following cluster. The inter-cluster spacing is the inter-vehicle spacing given that the distance is greater than R:

In a similar fashion we can take the expectation to get the expected Inter-cluster spacing:

#### Average Cluster Size

The average cluster size is also of importance. The method used to determine the average cluster size is to list the possibilities of the number of vehicles in a cluster before becoming disjointed. This forms a geometric series where the Probability Mass Function (PMF) can be calculated as follows:

We can recognize that the expectation of a standard geometric series of this form will lead us to the average cluster size.

#### Average Cluster Length

The average cluster length can be derived from a combination of the cluster size and intra-vehicle spacing.

## Analysis

The method used to measure the accuracy of the newly developed model against the empirical data is the Kolmogorov-Smirnov test (K-S test). This is a statistical test to compare the accuracy of sample data versus a reference probability distribution. In this case the K-S test will compare the empirical data collected by BHL and the derived CDF for the Inter-Arrival Time and Inter-Vehicle Spacing. Using the K-S Test we can measure the goodness-of-fit by:

|  |  |
| --- | --- |
|  | * is from the model * is from the empirical data |

In figure 6 we can see the results of the K-S test. The model is accurate to about 3% for both Inter-arrival time and Inter-vehicle spacing during the time period of 1-3am. We observe that the dashed blue lines (model) and the solid blue line (empirical) are very similar. However the model breaks down slightly when vehicles exceed 1000 vehicles/hour. This is not too much of a concern mainly because we are focusing on the time frame when network connectivity is not guaranteed (i.e. 1-3am). Table I and II show the exact D statistics calculated with the K-S test to further reinforce the illustration in figure 6.



|  |  |  |  |
| --- | --- | --- | --- |
| Table I  Kolmogorov-Smirnov Test Results of Inter-Arrival Time During Three Different Time Periods | | | |
| Time of Day |  |  |  |
| 01:00 am – 03:00 am | 429 | 0.1192 | (2.89, 2.00) |
| 10:00 am – 12:00 pm | 2619 | 0.7276 | (4.65, 4.00) |
| 15:00 pm – 17:00 pm | 2812 | 0.7813 | (8.23, 10.98) |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Table II  Kolmogorov-Smirnov Test Results of Inter-Vehicle Spacing During Three Different Time Periods | | | | |
| Time of Day |  |  |  |  |
| 01:00 am – 03:00 am | 30.93 | 0.1192 | 0.0039 | (2.65, 2.42) |
| 10:00 am – 12:00 pm | 29.15 | 0.7276 | 0.0250 | (3.13, 9.27) |
| 15:00 pm – 17:00 pm | 10.73 | 0.7813 | 0.0728 | (8.09, 9.67) |

## Performance Results

## Discuss Results

## Suggestion

# References

## [1] Routing in Sparse Vehicular Ad Hoc Wireless Networks

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