# Epidemic Density Adaptive Data Dissemination Exploiting Opposite Lane in VANETs

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# Abstract

Vehicular ad-hoc networks (VANETs) aim to increase the safety of passengers by making information available beyond the driver's knowledge. The challenging properties of VANETs such as their dynamic behavior and intermittently connected feature need to be considered when designing a reliable communication protocol in a VANET. In this thesis, we propose an epidemic and density adaptive protocol for data dissemination in vehicular networks, namely EpiDOL, which utilizes the opposite lane capacity with novel probability functions. We evaluate the performance in terms of end-to-end delay, throughput, overhead and usage ratio of the opposite lane under different vehicular traffic densities via realistic simulations based on SUMO traces in ns-3 simulator. We found out that EpiDOL achieves more than 90% throughput in low densities, and without any additional load to the network 75% throughput in high densities. In terms of throughput EpiDOL outperforms the Edge-Aware, DV-CAST and DAZL protocols 10% , 40%, 50% respectively. To achieve high throughput performance regardless to density level, we proposed a range adaptivity feature which utilize two channel statistics Channel Busy Ratio (CBR) and reception rate. This feature improved our throughput by 25% in higher densities.

# Özetçe

Araçlar arası ağlar sürücünün erişimi dışındaki bilgileri kullanarak yolcuların güvenliğini arttırmayı amaçlamaktadır. Fakat etkili ve güvenilir bir ağ kontrol protokolü tasarlamak için devamlı değişen ağ yapısı ve sürekli olmayan bağlantılar dikkate alınmalıdır. Bu çalışmada araçlar arası ağlar için, yeni geliştirilmiş olasılık işlevleri kullanarak karşı şeritteki araçlardan yararlanan, yoğunluk uyarlamalı, yayılımcı bilgi dağıtma protokolü (EpiDOL) öneriyoruz. EpiDol'un verimliliğini, SUMO ortamında yaratılmış gerçekçi trafik izleriyle ile ns-3 benzetimcisinde farklı yogunluktaki ağlarda benzetimledik. Bu benzetimleri verimlilik, uçtan uca gecikme, maliyet ve karşı şeritin kullanım oranı ölçütlerini kullanarak inceledik. Sonuç olarak EpiDOL'un az yogunluklu ortamlarda ,%90'dan fazla verimliliğe, yüksek yoğunluklu ağlarda ise herhangi bir ilave maliyet olmaksızın %75 verimliliğe ulaştığını gördük. Verimlilik bakımından karşılaştırıldığında EpiDOL daha önce önerilen Edge-Aware protokolünden %10 , DV-CAST protokolünden %40 ve DAZL protokolünden %50 daha başarılı olmuştur. EpiDOL'ün performansını attırmak için Kanal Yoğunluk Oranını ve paket alış hızını paratmetre olarak kullanan erim uyarlama özelliği ekledik. Bu özellik yüksek yoğunluklardaki verimliliğimizi %25 oranında iyileştirdi.

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# Chapter 1

# Introduction

## 1.1 Vehicular Ad-Hoc Networks

For improving safety of the roads, vehicular ad-hoc networks (VANETs) has become popular both in industry and academia. Efficient usage of vehicular networks has significant potential considering the fact that the amount of traffic accidents is massive. For instance, every year just in the United States almost six million traffic accidents, ten thousands of deaths and millions of injuries occur [1]. Certainly, VANETs are expected to significantly improve the safety of our transportation systems by making information available beyond the drivers' knowledge. In ad-hoc networks, routing protocols are crucial to maintain reliable and efficient communication. Despite this importance, most of the protocols offered for VANET are reinterpretations of the well known mobile ad-hoc network (MANET) routing protocols. However, VANETs behave in fundamentally different ways than the models that predominate in MANET researches. Unlike traditional MANETs, they have high but more predictable mobility models with rapid changes due to high speed and frequent fragmentation in network topology [2]. Geographic position information is available through Global Positioning System (GPS) with no power or hard delay constraints. Therefore, communication methods developed for VANETs must consider various dimensions including delay and reliability requirements, protocol specifications, vehicle mobility, topology characteristics and physical constraints. Thus, instead of using existing protocols proposed for MANETs, design of protocols specifically for VANETs to mitigate its disadvantages and utilize GPS information is needed.

## 1.2 Contributions

In this study, we propose and develop a novel data dissemination protocol for VANETs. In contrast to prior studies, our protocol EpiDOL uses epidemic routing by using the advantage of opposite lane as relaying with novel probability functions among vehicles. Epidemic technique introduces intelligence into data dissemination by reducing contentions and collisions while not requiring infrastructure support. Our probability functions are simple but effective in providing adaptivity to density. Therefore, the comparison of our approach with state of the art protocols DV-CAST [3], Edge-Aware [4] and DAZL [5] in realistic traces, proved the efficiency of EpiDOL in terms of lower delay, higher throughput rates and better utilization of opposite lane relaying. The novelties of this work are as following.

- We propose and develop a density adaptive epidemic data dissemination protocol, EpiDOL which uses only limited network information and control flags that indicate packet dissemination direction and vehicles' movement direction.

- In EpiDOL, we propose a new probabilistic approach to utilize opposite lane nodes as relay node to solve disconnected networks problem.
- We evaluate EpiDOL in various scenarios such as; different density levels, transmission rates, transmission ranges and varying background noise levels.
- To improve the performance of EpiDOL, we include a range adaptivity feature that utilizes channel busy ratio and reception rate.

The original contribution is to propose probabilistic density adaptive epidemic data dissemination protocol, EpiDOL. Also, we analyze the dependence of optimal parameters of epidemic routing on the density and the direction of vehicles. In addition, we evaluate the performance of EpiDOL compared with the current routing algorithms with simulations that use realistic traffic traces.

## 1.3 Organization

The rest of this thesis is organized as follows. Chapter 2 describes related works about routing protocols, probability functions and adaptivity approaches in VANETs. Chapter 3 describes the details of EpiDOL with performance metrics that we used during the simulations and discusses the system model of EpiDOL. Chapter 4 provides scenarios and results used in simulations and performance criteria. Chapter 5 concludes the thesis.

# Chapter 2

# Related Work

This chapter includes the details of previous works in VANETs.

## 2.1 General Overview

Distributing Internet on roads [6] or using mobile phones and in-car embedded devices for collecting and processing data [7] are possible applications of VANET. To realize these applications, we have to disseminate the data throughout a network. While thinking ad-hoc networks, the simplest and the most common way of data dissemination is flooding. However, as a result of the redundant broadcasts there may be contentions and collisions in the shared wireless medium. VANET routing protocols mainly deal with two problems, broadcast storm and disconnected networks [3]. When high number of nodes start to disseminate their packets at the same time, it is highly probable that the collisions will occur. The loss of data packets due to these collisions are defined as broadcast storm problem. [8] and [9] try to solve this problem in MAC layer level by including some new ideas such as disseminating packets with probability functions. [10] develops a scheme to distribute packets fairly to the network by using the local knowledge. We have further improved these approaches by introducing probability functions adaptive to density. EpiDOL uses epidemic approach with different probability functions succeeded to decrease the packet loss and overhead while increasing the throughput significantly.

According to [11] other challenges in VANET i.e. vehicle movements and driver's behavior cause rapid topology changes and frequent fragmentation on the network. Possible link breakages are predicted using the velocity of the nodes in [12] and [13]. We deal with these problems by using periodically updated neighborhood info. Additionally the dynamic behaviors of the vehicles and the sparsely connected networks introduce new problems. However it is already shown that Gossip-based (Epidemic) protocols are effective to solve these problems and provide reliable and efficient communication [14].

Reactive and proactive protocols have different behaviors under different traffic regimes [2], they should be robust to different density levels. [5] presents a zone-based forwarding scheme to deal with density problems. At low density networks the disconnected network problem is a severe issue. It can be defined as the case when there are not sufficiently enough nodes for data transmission in the network. It is proposed that by choosing the best packet structure this problem can be solved [12]. To deal with this problem, the proposal and successful implementation of the intelligible use of the vehicles in the opposite lane for relaying packets between disconnected networks in the original lane is another novel contribution of this work.

## 2.2 Epidemic Protocols in Ad-Hoc Networks

Epidemic protocols realize probabilistic information dissemination which do not require any knowledge of the network topologies ([15]). By using epidemic routing, a source node diffuses copies of a message to all nodes those it ever meets. These nodes will forward the message to all other nodes those have not been infected by this message. [4] proposes an algorithm related to epidemic approach which detects edges and sends packets with their own probability function. [16] work in Mobile Ad-Hoc Networks (MANETs), which proposes and idea about epidemic based multicasting. However, this work does not exploit VANET mobility model. [17] investigates the impact that network conditions and vehicle density have on the performance of epidemic dissemination and the correlation between these factors and other simulation parameters. Another proposed epidemic protocol is Edge-Aware in [4] which is discussed in section 2.5 along with DV-CAST [3] and DAZL [5].

## 2.3 Probabilistic Routing

[18] and [19] reinterpret well-known protocols AODV, GPSR and OLSR instead of proposing specialized approaches for VANET. Addition to this different techniques, Edge-aware Epidemic Protocol [4] is the most relevant study to this work. Edge-aware detects edge nodes and assigns high probabilities to these nodes. Additionally, according to Table 2.1, there are various probabilistic routing techniques. [20] uses hop counts and neighborhood size while generating GOSSIP1(p,k), GOSSIP2(p1,k,p2,n), GOSSIP3(p,k,m) and

GOSSIP4(p,k,ḱ) functions. In [21] standart probability functions Gaussian-like, Linear and Exponential-like are adapted to VANET. [22] and extended version [23] is an MANET approach which calculates probability dynamically by choosing $p_{max}$ and $p_{min}$. In [24] hop counts use in calculation of probability function. In [25] each message has node degree which is like hop count, in their probability function they use this value. They calculate the average number of neighbors at node $n_f$. They categorize the probability functions according to the average number of neighbors value, then they use this category number in their probability function. However, EpiDOL extends these approaches with its opposite lane usage and simple but effective probabilistic forwarding technique.

| **Reference** | **Network Type** | **Probabilistic Flooding Approach** |
|---|---|---|
| [20] | VANET | According to hop counts and neighborhood size different functions are used for probabilistic flooding. |
| [21] | VANET | 3 different standart probability functions are adapted to VANETs. Functions are:<br>Gaussian-like: $p = e^{d^2/2\alpha^2}$<br>Linear: $p = 1 - (1.3d/3r)$<br>Exponential-like: $p = e^{-0.7d/r}$ |
| [22] | MANET | Probability is calculating dynamically, $p_{max}$=1 and $p_{min}$=0.4. Unique packets are sending with probability $\prod_{i=0}^{S_{nbr(i)}} P * P_{max}$. |
| [23] | MANET | Extended version of [22]. $p_{max}$ and $p_{min}$ are chosen respectively 0.9 and 0.4. Unique packets are sending with probability $P_{max} * \sum_{n=0}^{nbr} P_{max}^{n}$ |
| [24] | MANET | According to their specified time constraint, message is rebroadcasting with the $P(t_i) = \frac{1}{(n+1) - \frac{i}{3} * n}$ where $i = 0, 1, 2, 3$. |
| [25] | MANET | General probability function is $p = \frac{p_f}{r}$ , r is category number. |

**Table 2.1:** Probabilistic Flooding Literature Review

## 2.4 Power Adaptivity

Power change is a kind of approach for controlling the load in the radio channel. In PULSAR [26], transmission power is changed with the agreement of 2-hop neighbors. In contrast with this, [27] each vehicle makes its own decision on transmit power independently by calculating average reception rate. In another dynamic power control algorithm, Efficient Transmit Power Control (ETPC) [28], all vehicles adjust their power according to the power of the selected victim vehicle by using beacon load rates. On the other hand, in EpiDOL, adaptivity algorithm is aiming to hold channel busy ratio (CBR) in a certion level by changing the range.

## 2.5 Compared Protocols

To prove the efficiency of EpiDOL, we compared it with state of the art data dissemination protocols designed for VANET, namely Edge-Aware [4], DV-CAST [3] and DAZL [5]. Edge-Aware is also an epidemic protocol that utilizes the GPS information. Basically it calculates the probability of rebroadcasting $P$ as

$$P = \begin{cases} 1, & if\ N_f\ \ or\ N_b = 0 \\ 1 - exp\left(-\alpha \frac{|N_f - N_b|}{N_f + N_b}\right), & otherwise \end{cases} \tag{2.1}$$

where $N_f$ and $N_b$ are the number of times the car has received that particular message from front and from back respectively. With this approach, they have managed to give higher probabilities to vehicles near the head or tail of a cluster. However, they have not proposed a specialized function to use opposite lane that can increase the connectivity and the throughput considerably for disconnected networks as we proved in this work. Also, the proposed protocol is only compared with simple flooding protocol in a controlled scenario rather than realistic traces.

DV-CAST [3] is a distributed broadcast protocol that utilizes opposite lane vehicles. By exchanging GPS information, every vehicle classifies its network as a well connected, sparsely connected or totally disconnected network. Then depending on this classification, vehicles set the values for three flags, MDC (message direction connectivity), DFlg (direction flag) and ODC (opposite direction connectivity). For different combinations of these flags, DV-CAST takes different actions such as broadcast suppression, rebroadcast, packet relaying, carry and forward and wait and forward. However, the simulations of this protocol is only limited with controlled circular highway scenario that lacks realistic traces such as SUMO traces.

DAZL [5] is a new forwarding protocol that combines three concepts. First one is the cooperation of multiple nodes in packet forwarding which provides robustness to the topology changes. Second one is control of duplication and contention in high density scenarios by using network-layer slotting. Third one is for maximizing the hop length distributed prioritization algorithm is used. However, their delay is high because of the background calculations.

Compared to these three protocols, in EpiDOL we use not only epidemic approach but also add some intelligence by making system robust to the density changes. To achieve an objective comparison, we use the metrics defined in Chapter 3.3.

# Chapter 3

# EpiDOL Protocol and Parameter Optimizations

This chapter explains the details of our approach, EpiDOL. In section 3.1 we establish our system model on which our algorithm is based. This is followed by the algorithm description along with the system architecture and probability functions that constitute the essence of the EpiDOL. In the last part we optimize the parameters of the aforementioned probability functions in given scenarios.

## 3.1 System Model

We consider an ad-hoc network with randomly distributed vehicles on a multilane bidirectional highway. Each vehicle is equipped with GPS and has the communication capability with 802.11p protocol [29]. We assumed that the nodes are only interested in the packets that are generated by nodes that lead them within less than a certain region of interest (ROI). All packets are generated by a leading node with the same priority and the same dissemination distance. Any packet can be lost due to collisions, however, if a packet is received successfully, then there are no bit errors that lead to the misinformation of the node.

Since there is no central control or clustering mechanism, all nodes in the network act independently. They are only aware of their neighbors' locations and directions by periodical updates which will be discussed. It is assumed that any further information about the network topology or density are not available to the vehicles.

## 3.2 Algorithm Description

In this section, we describe principles of EpiDOL with its system architecture and probability functions.

### 3.2.1 System Architecture

In our approach, we aim to create an intelligent packet dissemination system by using flags on application layer. We use two binary flags: *of* shows the actual dissemination direction of the data packet, and *df* shows the vehicles riding direction with respect to the direction of the source node. With the help of the information that we gathered from these flags, the opposite lane is used effectively to provide the data connectivity and propagation.

Unnecessary packet dissemination is obstructed by using density adaptive probability functions $p_{same}$, $p_{opp}$ and $p_{sameToOpp}$ (Fig. 3.1) which are the probabilities of forwarding packets in the same direction, in the opposite direction and transmitting packets from original direction to the opposite direction, respectively. This approach solves the broadcast storm problem by decreasing the collision rate. We have information about neighbors of each node by sending hello packets periodically. The neighbor number provides a simple but effective density adaptation in the algorithm.

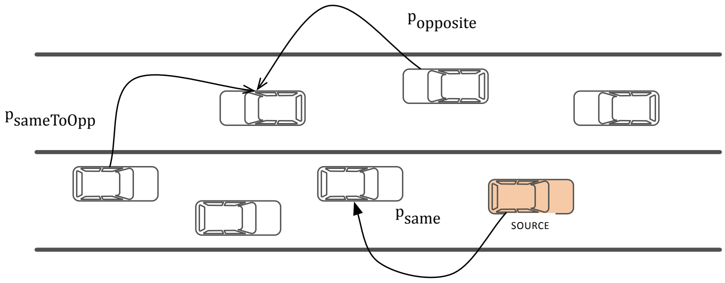


**Figure 3.1:** Usage of probability functions

In our system, there exist two types of packets. One of them is the periodic hello packet that includes source id, x-y coordinates of the source and its traveling direction. When hello packets are received, the receiver node creates its neighborhood list which includes information about its neighbors. Hello packets are like control packets. By using this method, we can easily manipulate the number of neighbors and their locations. The second type is data packet which includes the senders' id, x-y coordinates, the packet dissemination distance, the direction flag and the original flag. The dissemination distance shows how far the data packet should be propagated.

Algorithm 1 shows the decision phases of flag values in EpiDOL. While the vehicle is moving in the packets' dissemination direction (Line 1-2), if there are any same directional neighbors (Line 3), it means that packet will propagate in the original side, $of$ is 1 (Line 4). Additionally, for providing

| **Abbreviation** | **Explanation** |
|---|---|
| *df* | Direction flag |
| *of* | Original flag |
| *neighSame* | Number of same directional neighbors |
| *neighOpp* | Number of opposite directional neighbors |
| *myDir* | Direction of the current node |
| *sourceDir* | Direction of the source node |

**Table 3.1:** Abbreviations used in algorithm

the continuity of the packet dissemination, EpiDOL sends this packet to the opposite directional vehicles (Line 5) by setting the $of$ and *df* to 0 (Line 6). Another case is when the value of *df* is 0 (Line 9-10). This shows that vehicle is moving in the opposite direction of the packets' dissemination. If there are any same directional neighbors (Line 11), packet is sending to them with the same flag values (Line 12). If there are any opposite directional neighbors (Line 13), which are actually in the original side, $of$ value is set to 1 (Line 14), showing that the packet returns its original directional side.

### 3.2.2 Probability Functions

The decision of forwarding a packet or not is taken by a probabilistic manner at each node independently. Prior to the each packet transmission, a probability that estimates the necessity of the transmission of a packet from a particular node is calculated with the help of the number of total neighbors. We assumed that the more the neighborhood number is, the higher the chance of nodes receiving the data packet. With this assumption in mind the most trivial probability function is $p = 1/N$, where N is the number of neighbors,

**Algorithm 1** Flag Value Decision

```
algorithm executed after each data packet arrives
if $df = 1$ then
    while $myDir = sourceDir$ do
        if $neighSame > 0$ then
            set $of = 1$ and $df = 1$
        else if $neighSame = 0$ and $neighOpp > 0$ then
            set $of = 0$ and $df = 0$
        end if
    end while
else if $df = 0$ then
    while $myDir \neq sourceDir$ do
        if $neighSame > 0$ then
            keep flag values same
        else if $neighSame = 0$ and $neighOpp > 0$ then
            set $of = 1$ and $df = 0$
        end if
    end while
end if
```

however it can easily be proven that this function will not perform good in dense networks. Within a neighborhood with $N$ nodes, the probability of a packet which is not transmitted by a particular node is $p^c = 1 - 1/N$. In homogeneously distributed dense network, we can safely assume that there are no clustering, so each node will approximately have the same number of neighbors. Since each node decides independently with the assumption of a packet is received by N nodes the probability of a packet not forwarded by any nodes is;

Let $N = \#ofNeighbors$. Then,

$$p_N^c = \left(1 - \frac{1}{N}\right)^N \tag{3.1}$$

If we take the limit of this probability as $N$ goes to infinity, to see the probability of a packet being not forwarded by any nodes in a dense network,

$$\begin{aligned}\lim_{N \to \infty} p_N^c &= \lim_{N \to \infty} \left(1 - \frac{1}{N}\right)^N \\ &= \lim_{N \to \infty} \left(\frac{1}{e} - \frac{1}{2eN} - \frac{5}{24eN^2} + ...\right) = \frac{1}{e} \approx 0.37\end{aligned} \tag{3.2}$$

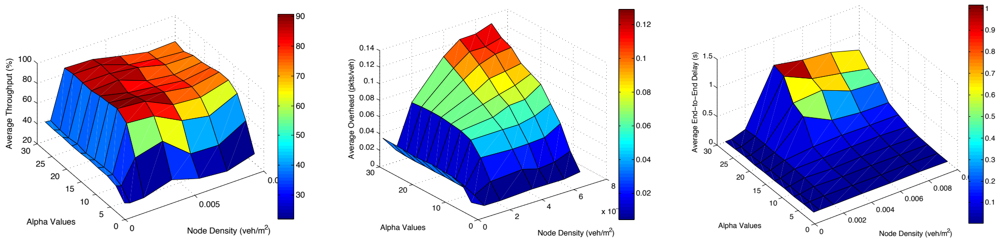
This shows that, in dense networks since $p$ is so small, the dissemination of the packet will be stopped with approximately 0.37 probability. In real life, due to collisions in a dense network, the number of nodes that receive a packet is much less than N. Consequently the probability of a packet not forwarded by any nodes is even higher than 0.37. For avoiding these situations, we multiply our value with $\alpha$ parameter. So we choose $p = \frac{\alpha}{N}$ which decreases the $p_N^c$ to $\frac{1}{e^\alpha}$ for large $N$. Note that the case of $p > 1$ is treated as if $p = 1$. Both $p_{same}$ and $p_{opp}$ are calculated with this function. However, according to our simulations, we detected that the best $\alpha$ values are different for propagating packets in the original and in the opposite directions. Thereon we use 2 different $\alpha$ values; $\alpha_{same}$ and $\alpha_{opposite}$ which are optimized by evaluating the different $\alpha$ values on various scenarios.

The decision of using opposite lane nodes as relay nodes not only depends on the number of neighbors but also depends on the spatial distribution of the nodes around. The extreme case is the vehicles at the rear end of a cluster. Basically they will have large number of neighbors due to number of vehicles that lead them, however these neighbors are not helpful for propagating packets to backward direction. With this intuition we proposed the following Algorithm 2 to decide on usage of opposite lane nodes. Therefore, the corresponding $p_{sameToOpp}$ is equivalent to $P\{\#BackwardNeighbors \leq$

$backwardValue\}$. This function helps to solve the disconnected networks problem by continuing the packet dissemination using opposite sided vehicles as relaying nodes. Backward functions use Algorithm 2. In this function, only vehicles in the rear end of a connected cluster are sending packets to the opposite lane.

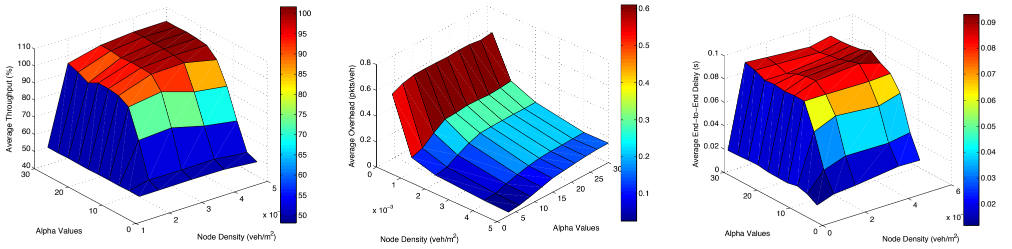
**Algorithm 2** Backward Function

```
algorithm executed after each data packet arrives
if $NumberOfBackwardNeighbors \leq backwardValue$ then
    send with $p = 1$
else
    $p = 0$
end if
```



**(a)** Throughput Graph **(b)** Overhead Graph **(c)** End-to-end Delay Graph

**Figure 3.2:** Choosing optimal $\alpha_{same}$



**(a)** Throughput Graph **(b)** Overhead Graph **(c)** End-to-end Delay Graph

**Figure 3.3:** Choosing optimal $\alpha_{opposite}$

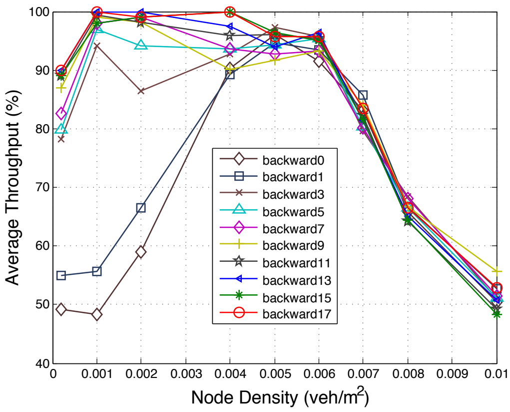


**Figure 3.4:** Throughput for Backward Functions

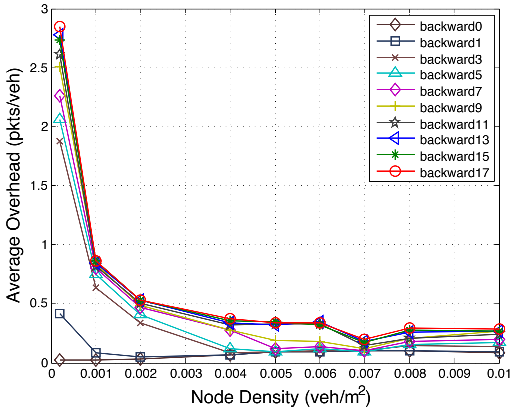


**Figure 3.5:** Overhead for Backward Functions

## 3.3 Implementation

In our simulations, we use SUMO [30] for generating realistic low and high density traces. The simulation environment is ns-3 [31]. According to [32], the typical transmission range is 400 meters. We consider a network with randomly distributed vehicles over a 6-lane bidirectional highway. Our region of interest (ROI) has a length of 5km. Since we assumed that there are not any intersections in our ROI, neither death nor birth of a node are allowed. To imitate the dynamic behavior of a highway, the speeds of the vehicles are uniformly distributed from 80km/h to 120km/h.

### 3.3.1 Performance Metrics

EpiDOL is designed for merging epidemic approach with highly mobile ad-hoc networks. In order to evaluate its reliability and efficiency, we use the following performance metrics. Moreover, these metrics also enable an objective comparison of our proposed algorithm with other approaches.

- **End-to-End Delay:** Time taken for packet transmission from source to nodes which are in the range of dissemination distance. For each packet received by every node, it is given by;

$$\textit{End-to-End Delay} = t_{receive} - t_{firstSending} \tag{3.3}$$

- **Throughput:** This parameter shows the rate of successfully received packets by all nodes which are in the dissemination distance. Calculation is as follows:

$$\textit{Throughput} = \frac{\#\textit{received packets for each node}}{\#\ \textit{all transmitted packets}} \times 100 \tag{3.4}$$

- **Opposite Lane:** This parameter measures how many times opposite lane nodes resend the packets that are taken from the original side (Fig. 3.6). Calculation is as follows:

$$\textit{Opposite Lane} = \frac{\#\textit{packets sent by opposite directional nodes}}{\#\ \textit{all packets}} \times 100 \tag{3.5}$$

- **Overhead:** The number of duplicate packets received during the simulation. The overhead is simply equal to the number of received duplicate packets at each node.

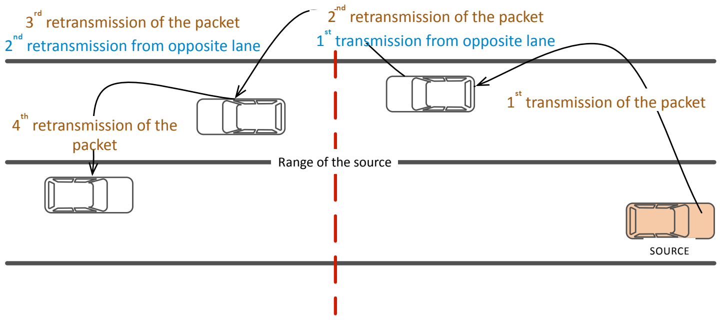


**Figure 3.6:** Explanation of opposite lane usage calculation

## 3.4 Parameter Optimizations

### 3.4.1 Optimization of $\alpha_{same}$

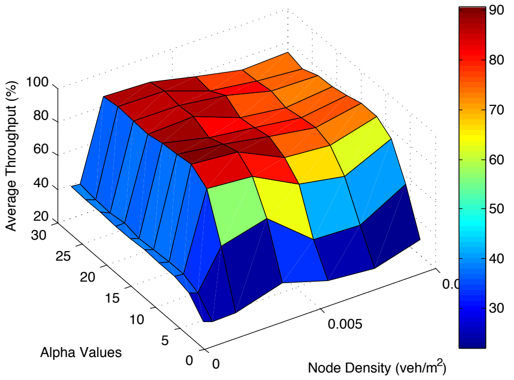
For optimization of the $\alpha_{same}$ value, we generated SUMO traces which include 10 to 500 vehicles ride in the same direction. Changing $\alpha$ values from 3 to the 30, we produced 3D graphs in Fig. 3.7. According to these results, $\alpha_{same}$ is chosen as 15, since 90% throughput is achieved while the end-to-end delay is less than 0.06s and the overhead is lower than 0.07. $\alpha_{same}$ being equal to 15 ensures if we have less than 15 vehicles within the coverage area, all nodes will try to forward packets. This is desirable in a sparse network, since at low density our main concern is the survival of the packet rather than the packet collisions. Besides, as the neighbor numbers increase and $p_{same}$ decreases the expected number of retransmissions in a certain area will remain around 15. As seen in Fig. 3.7b, after a certain node density the overhead does not increase at all for $\alpha_{same} = 15$. This supports our claim about our $p_{same}$ being sensitive to node density in the network. It is obvious that the performance can be increased with the perfect knowledge of the network density. However, due to excessive control packets, acquiring this information will increase the network overhead significantly, that might even decrease the overall throughput.

### 3.4.2 Optimization of $\alpha_{opposite}$

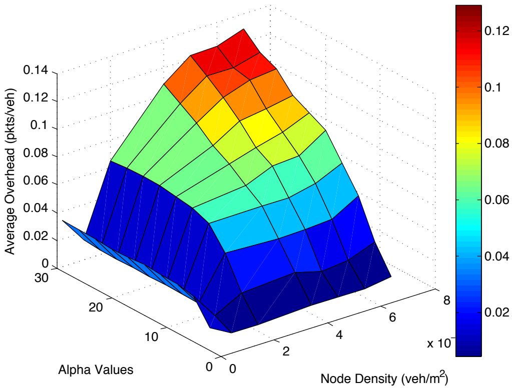
For optimization of the $\alpha_{opposite}$ value, we generated SUMO traces which include 10 to 300 vehicles in the opposite direction and 60 vehicles in the original (same) direction. For $\alpha$ values from 3 to 30, the results are shown in Fig. 3.8. According to these results, $\alpha_{opposite}$ is chosen as 21, since 97% throughput is achieved while end-to-end delay is less than 0.1s and overhead is lower than 0.1. The optimal $\alpha_{opposite}$ being more than $\alpha_{same}$ is reasonable since we need more persistent transmissions to carry packets in between disconnected networks. Also Fig. 3.8a shows that even in really low densities, the utilization of the nodes in the opposite direction can double the throughput with $\alpha_{opposite}$ equals to 21. This proves that the regardless of the number of nodes in the opposite direction, we should use them as relay nodes.

### 3.4.3 Optimization of $backwardValue$

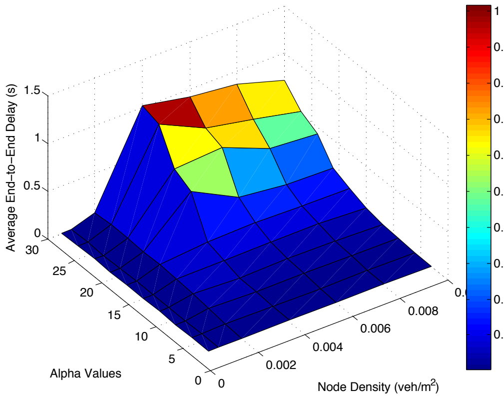
$backwardValue$ is used as a threshold in calculation of the $p_{sameToOpp}$ which decides whether sending packets from the original side to the opposite side or not.



**(a)** Throughput Graph

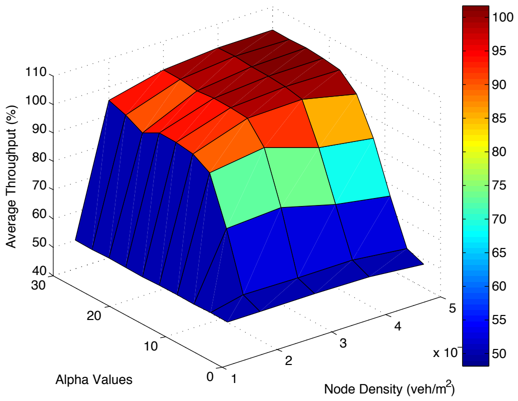


**(b)** Overhead Graph

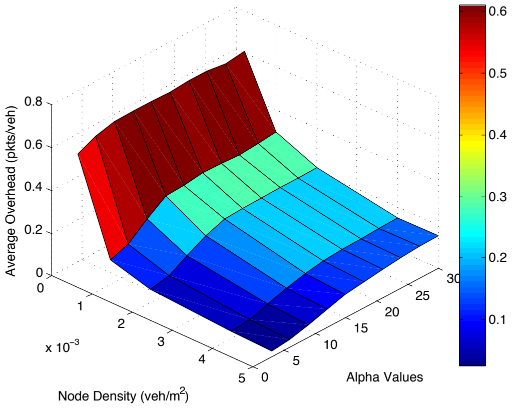


**(c)** End-to-end Delay Graph

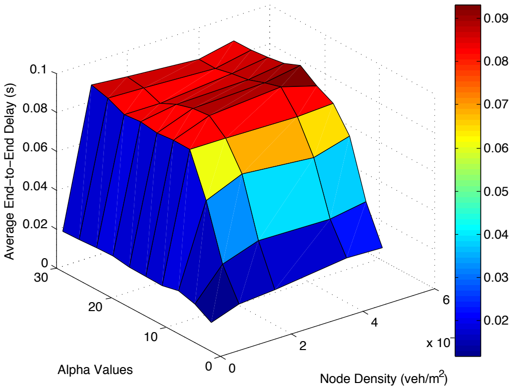
**Figure 3.7:** Choosing optimal $\alpha_{same}$



**(a)** Throughput Graph



**(b)** Overhead Graph



**(c)** End-to-end Delay Graph

**Figure 3.8:** Choosing optimal $\alpha_{opposite}$

Consequently, choosing the best $backwardValue$ is crucial for the performance of the algorithm. To reason about and select the optimal $backwardValue$, we simulated networks with different densities using $backwardValue$'s from 0 to 17. Fig. 3.9 compares the throughput rates with different $backwardValue$'s. However we should focus the part where node density is less than $3 \times 10^{-3}$. At higher densities, opposite lane usage does not really improve the throughput, since we do not observe disconnected networks problem anymore, consequently all $backwardValue$'s converge to same throughput levels. However, the average overhead for densities higher than $3 \times 10^{-3}$ does not significantly differ for different $backwardValue$'s as shown in Fig. 3.10. At high density conditions, the necessity of using opposite lane decreases. According to our function, the number of eligible vehicles which send packets to opposite lane also decreases while the density increases. In summary, by using the appropriate $backwardValue$ we can double the throughput in low densities in return of higher overhead, however our main concern is to maintain connectivity rather than overhead in low densities. On top of this for higher densities, even though backward function can not improve the throughput, it also does not significantly increase the overhead which is the limiting factor. This proves the density adaptivity of our approach. To decide the optimal value of $backwardValue$, we have to consider Fig. 3.9 and Fig. 3.10 simultaneously. According to Fig. 3.9, to achieve 90% throughput in lower densities, $backwardValue$ should be higher than 9. However, for $backwardValue$'s greater than 9, the throughput does not increase at all. Furthermore, considering overhead values of Fig. 3.10 for several different vehicle densities, the optimum $backwardValue$ is determined as 11. As shown in Fig. 3.11, an evaluation of this $backwardValue$ along with two others has been performed and these results indicate the density adaptive nature of opposite lane usage ratio with the probability function making use of number of backward neighbors.

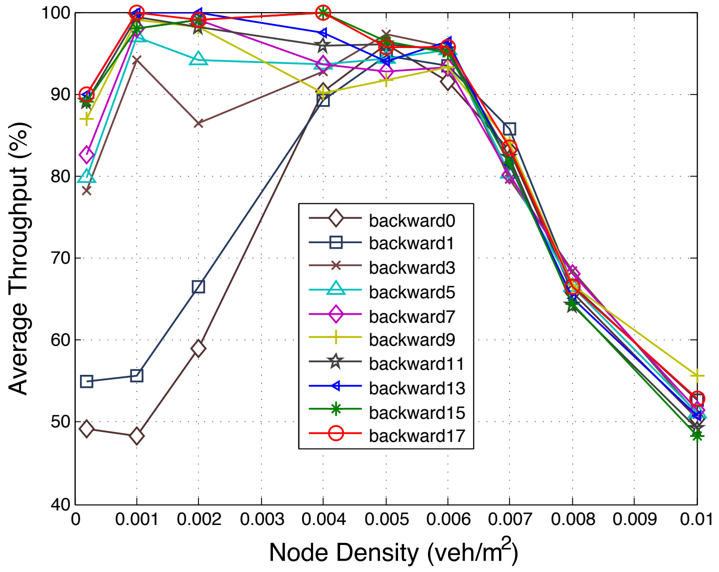


**Figure 3.9:** Throughput for Backward Functions

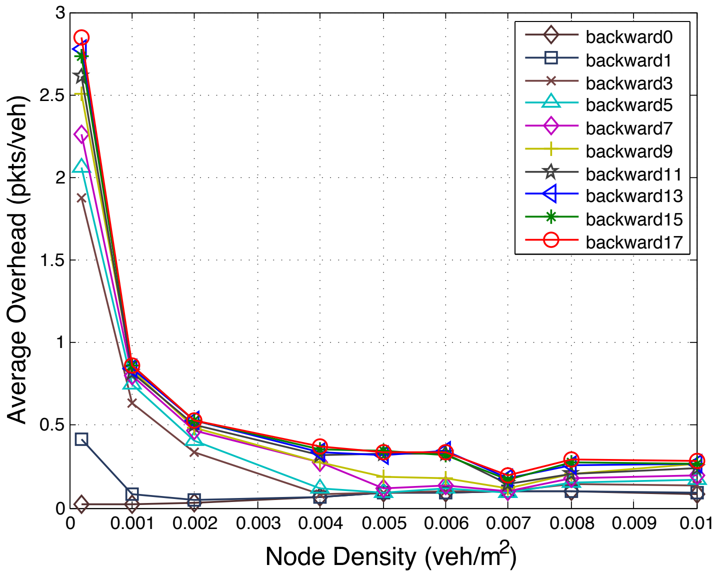


**Figure 3.10:** Overhead for Backward Functions

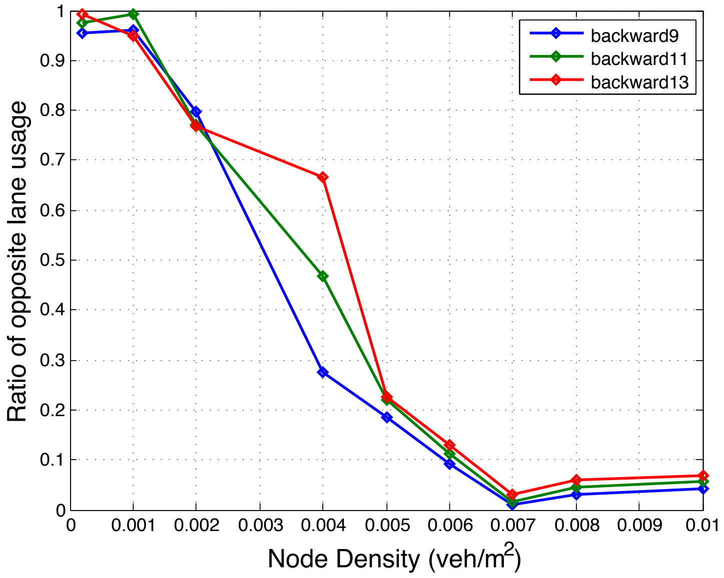


**Figure 3.11:** Opposite Lane Usage Ratio

# Chapter 4

# Performance Results and Adaptivity Features

In this chapter, first we consider the effect of background noise on EpiDOL. Then, we include a transmission range adaptivity feature to increase throughput and reliability of EpiDOL. At last, we compare the performance of the EpiDOL with state of the art VANET Protocols.

## 4.1 Background Traffic

For showing the robustness of the EpiDOL, we add background traffic to our simulations. We send 1KB sized FTP packets with 1, 0.1 and 0.01 second frequency. Fig. 4.1 shows the effect of background traffic on throughput. Sending FTP packets in every 0.01 second effects clearly, throughput is decreasing. However, under the rest of the background traffic, there is not any significant difference. This shows that, unless its heavy, background traffic does not effect EpiDOL clearly. By the way, according to this throughput ratios, higher background traffic simulation have lower overhead (Fig. 4.2), end-to-end delay (Fig. 4.3) and opposite lane usage (Fig. 4.4).

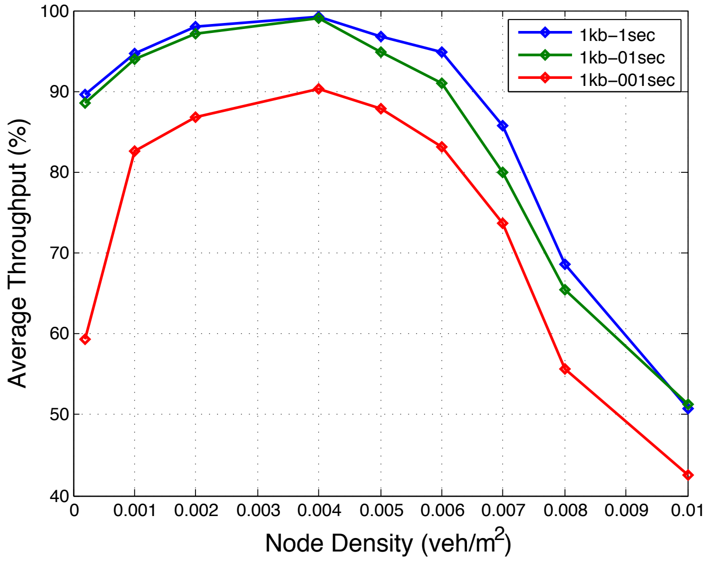


**Figure 4.1:** Background Traffic Effect on Throughput

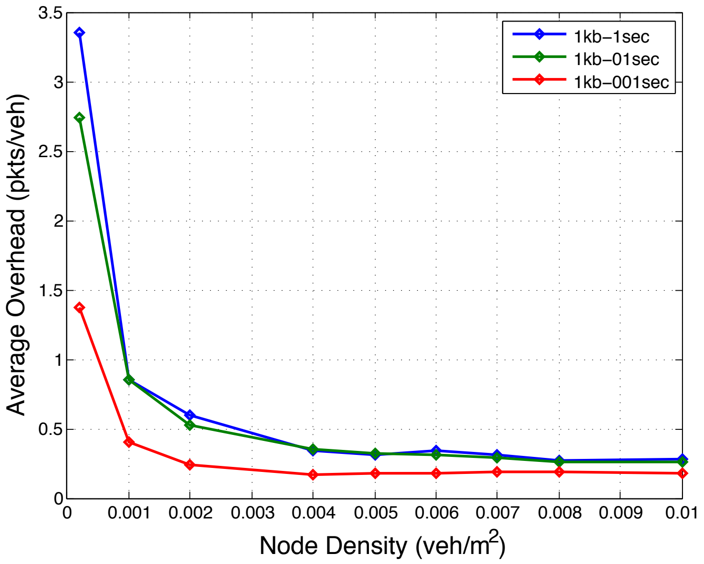


**Figure 4.2:** Background Traffic Effect on Overhead

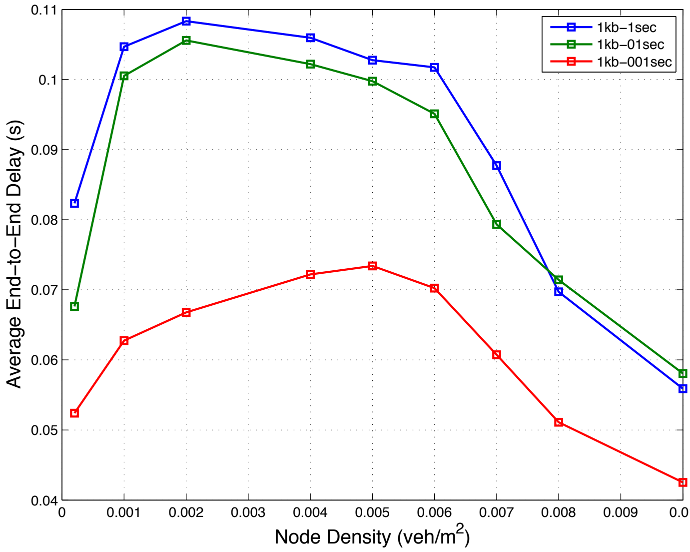


**Figure 4.3:** Background Traffic Effect on End-to-end Delay

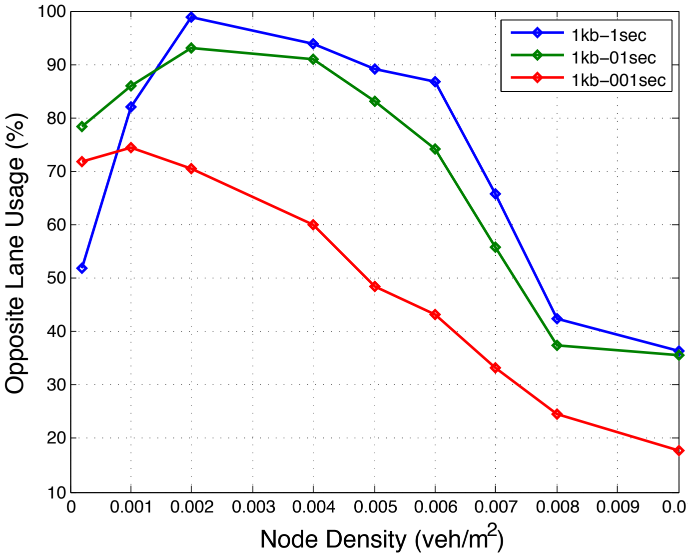
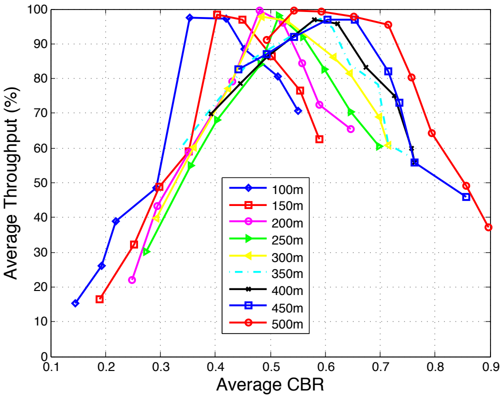
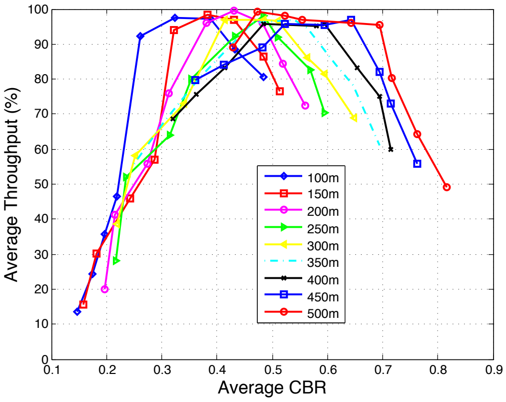


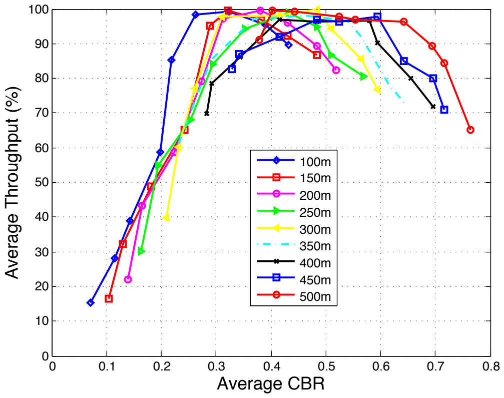
**Figure 4.4:** Background Traffic Effect on Opposite Lane Usage



**(a)** 0.3 sec/packet



**(b)** 0.5 sec/packet



**(c)** 1 sec/packet

**Figure 4.5:** Throughput-Average CBR Relation

## 4.2 Range Adaptivity

In this version of EpiDOL, we include a transmission range adaptivity feature to achieve the maximum possible throughput at different densities and data rates. To realize this we use Channel Busy Ratio (CBR) information which is the ratio of the busy time of the channel over all time. Each node calculates CBR individually before the packet transmission. To understand the relationship between CBR and the throughput with different transmission ranges we created Fig. 4.5. Eventhough the highest throughput is detected at different CBR values, the overall throughput performance for all scenarios are quite good when the CBR is between 0.4 and 0.7. So we proposed the Algorithm 3 to keep CBR in this range to achieve higher throughout on the overall. If the calculated CBR is higher than the 0.7, decrease the transmission range (Line 1-2). If the CBR is lower than the 0.4, this means that we need to increase the CBR value by increasing the range (Line 3-4). If the CBR is between the target values, send the packet (Line 5-6).

**Algorithm 3** Adaptivity with CBR

```
algorithm executed before packet sending
 100 meters ≤ range ≤ 500 meters
x = calculated CBR
y = 25 meters, 50 meters, 75 meters
1: if $x > 0.7$ then
2:     decrease range with y
3: else if $x < 0.4$ then
4:     increase range with y
5: else
6:     send packet
7: end if
```

We repeated same simulation with different packet generation frequencies

**Algorithm 4** Adaptivity with CBR and Reception Rate

```
algorithm executed before packet sending
100 meters ≤ range ≤ 500 meters
x = calculated CBR
r = reception rate
if $x > 0.7$ then
    if $r < 1$ then
        decrease range with 75 meters
    else
        decrease range with 25 meters
    end if
else if $x < 0.4$ then
    increase range with 25 meters
else
    send packet
end if
```

resulting different data rates. In Fig. 4.5a, Fig. 4.5b and Fig. 4.5c we set the period of packet generation at 0.3, 0.5 and 1 sec. Having good throughput in the same CBR range proves the reliability of the Algorithm 3 at different data rates.

We evaluated Algorithm 3 by using three different step sizes, 25 meters, 50 meters and 75 meters. The 25 meter step size provided the highest throughput (Fig. 4.7) and the best utilization of the opposite lane(Fig. 4.10). However it resulted in a high overhead (Fig. 4.8) and a high end-to-end delay (Fig. 4.9). Since we are more concerned about achieving higher throughput levels, we have chosen 25 meters as our step size. Nevertheless this value can be modified easily depending on the primary concern of the designer.

For increasing the efficiency of the algorithm, beside of the CBR parameter we add reception rate. Reception rate is successfully received packets in 1 second period of time. Like in CBR, we find interval for reaching the highest

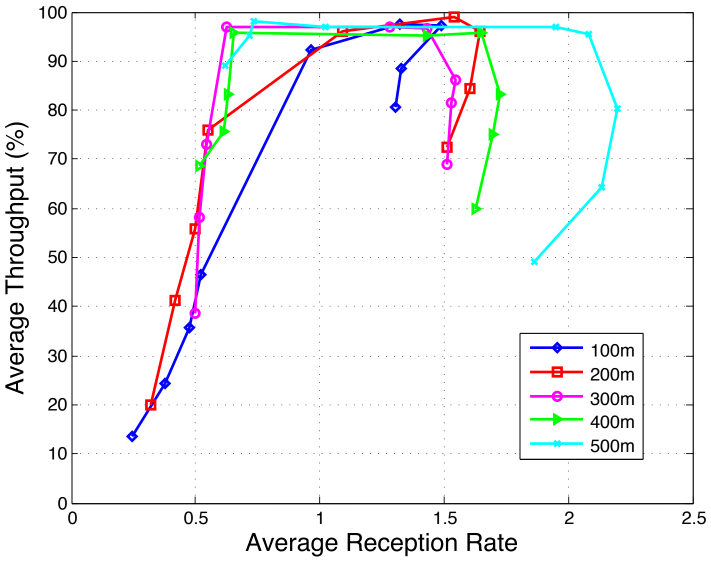


**Figure 4.6:** Throughput-Average Reception Rate Sending Packets 0.5 sec/pkt

throughput (Fig. 4.6) which is 1 to 1.5. However the shape of the curves shows that the relationship between reception rate and the throughput is not one-to-one. For example when we investigate the different points on 100m curve we can see that 1.3 packets/sec reception rate may correspond to either %97 or %80 throughput. In other words reception rate can not be used as a sole parameter to control transmission rate. However when we combine the results from Fig. 4.5 and Fig. 4.6, we can use the reception rate as a second phase controlling parameter (Algorithm 4). If CBR is lower than the threshold, regardless of reception rate is low or high we increase the range since the network have low density. If CBR is higher than the threshold this means that network have high density and there may have collisions. To detect this, we use reception rate. If the reception rate is lower than 1 with high CBR, this shows that there are high number of packet losses because of collisions. To avoid this packet losses, we decrease the range more rapidly. So, If the reception rate is lower than 1, we need to increase this value by decreasing the range rapidly, 75 meters (Line 2-3). In the reverse condition, decrease with 25 meters (Line 4-5). According to Algorithm 4, normally we change the range with 25 meters in simulation. However since high CBR with low reception rate is indication of high number of collision in the channel, we change the range more drastically (75 m.) to recover from this severe condition more quickly.

Even though this version of algorithm does not affect the throughput in low density but it improves the throughput significantly in high densities (Fig. 4.7). Algorithm 4 is 5% better than Algorithm 3 at high densities. In return of the gain in the throughput out overhead increases Fig. 4.8. This results in more energy consumption. However since energy constraints on VANET are not as strict as constraints MANET, this cost is affordable for such an improvement in throughput. Fig. 4.9 shows a slight increase in the end-to-end delay compared to Algortihm 3. Neverthless this increase is mostly dominated by the delays of the nodes at the perimeter which weren't connected earlier. Additionally in Fig. 4.10, the opposite lane usage increases with Algorithm 4 which indicates a better utilization of the nodes in the opposite lane.

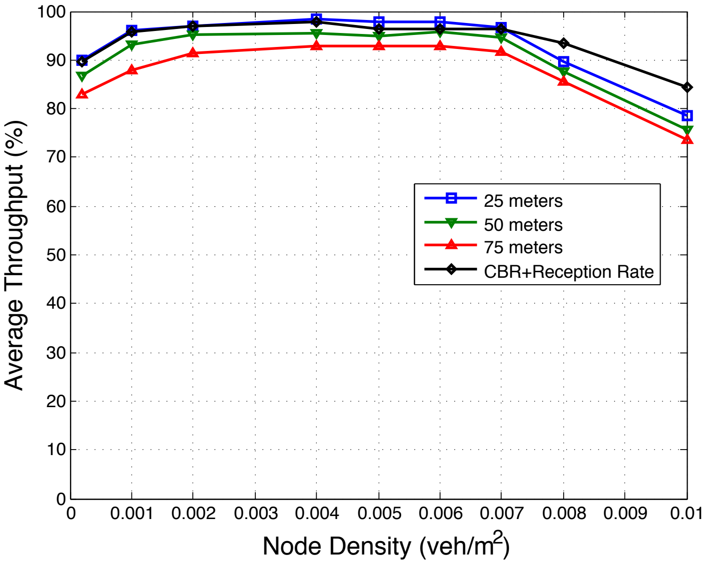


**Figure 4.7:** Throughput with Range Adaptivity Functions

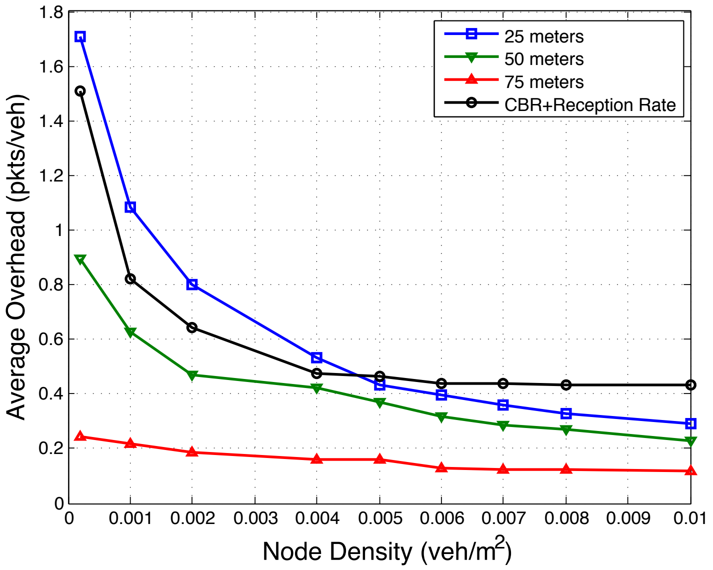


**Figure 4.8:** Overhead with Range Adaptivity Functions

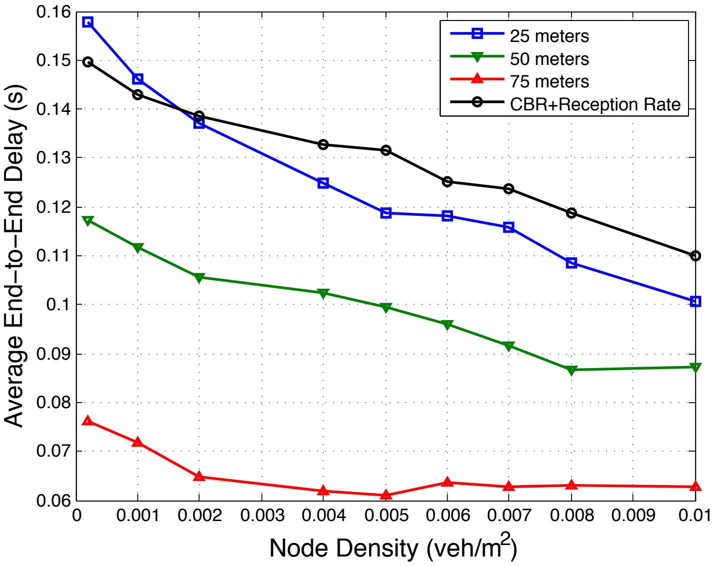


**Figure 4.9:** End-to-end Delay with Range Adaptivity Functions

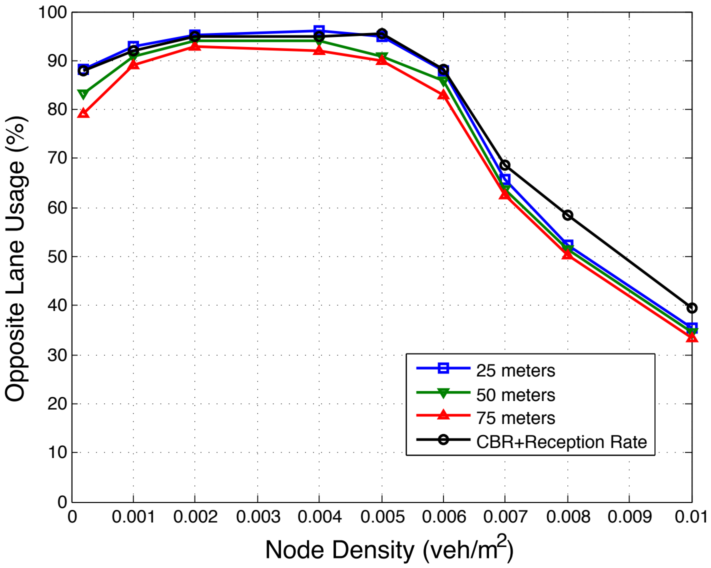


**Figure 4.10:** Opposite Lane Usage with Range Adaptivity Functions

## 4.3 Comparative Results

We have compared the selected protocols in ns-3 with realistic SUMO traces by using 10 random runs. Our results are shown in Figures.4.11-4.14.

Fig. 4.11 shows the ratio of successfully received packets by all same directional nodes in terms of percentage. Error bars in the figure show standard deviations around averages. In low densities, only EpiDOL and extended version of the EpiDOL achieve more than 90% throughput. Higher opposite lane usage shown in Fig. 4.14 ensures higher throughput. This proves that our protocol handles the disconnected network problem more effectively than the other protocols. According to Fig. 4.13, end-to-end delays of all protocols are comparable. Since DV-CAST can not distribute packets to the whole network, it is expected to see lower end-to-end delays. However, end-to-end delay of the EpiDOL with adaptivity function is high, this is because of the extra controls for range and changing the range. Like overhead of EpiDOL is lower than Edge-aware but higher than DV-CAST and DAZL as shown in Fig. 4.12. However, in these densities our main concern is maintaining connection between disconnected networks rather than overhead.

In high densities, as seen in Fig. 4.11 throughput of the EpiDOL with adaptivity feature using reception rate is 25% better than the other protocols including the raw version of the EpiDOL. This shows us adaptivity function solves the packet loss problem because of the collisions. Fig. 4.12 shows that this improvement is realized without introducing additional overhead to the network. EpiDOL has managed to deliver packets to higher number of nodes with comparable end-to-end delays as seen in Fig. 4.13. Moreover, EpiDOL+Reception Rate has acceptable end-to-end delay while achieving higher throughputs with low overheads in high densities which shows that EpiDOL+Reception Rate was able to deal with broadcast storm problem.

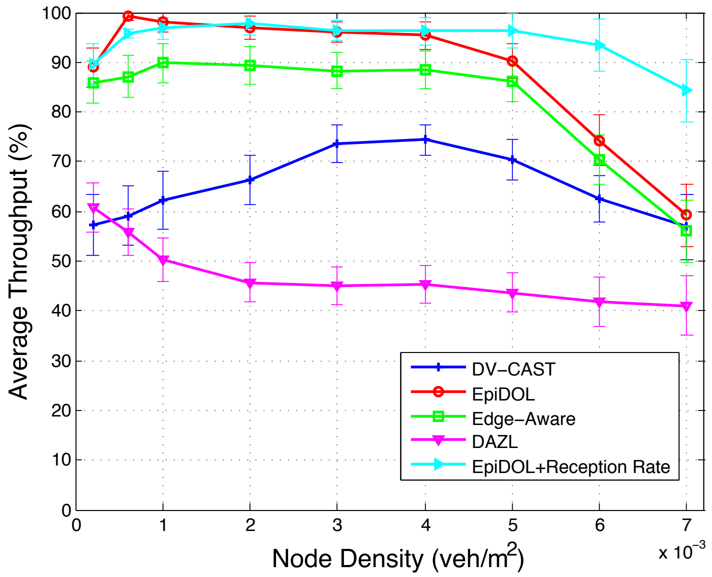


**Figure 4.11:** Comparison of throughputs

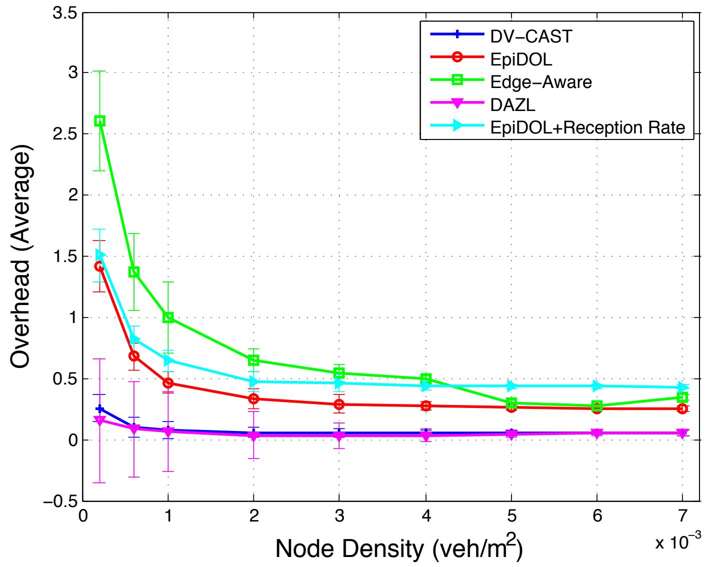


**Figure 4.12:** Comparison of overheads

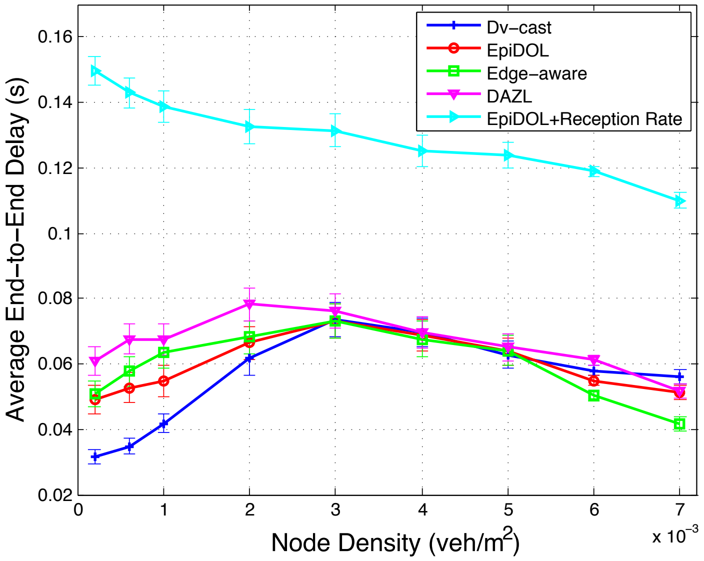


**Figure 4.13:** Comparison of end-to-end delays

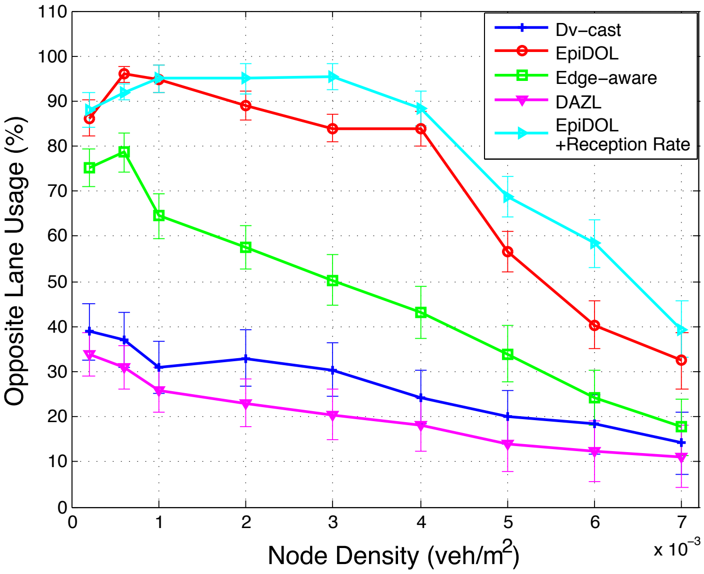


**Figure 4.14:** Comparison of opposite lane usage

# Chapter 5

# Conclusion

We proposed EpiDOL which is an epidemic and density adaptive protocol for data dissemination in VANETs that utilizes the opposite lane capacity with novel probability functions. We have optimized parameters of the algorithm based on analysis by using real traffic traces. We compared the performance of the proposed algorithm with the existing algorithms in terms of end-to-end delay, overhead, throughput and opposite lane usage.

According to results in low densities we achieved more than the 90% throughput with comparable end-to-end delay, overhead and opposite lane usage. This showed that EpiDOL handled the disconnected network problem. In high densities, without excessive values in end-to-end delay and overhead, throughput achieved by EpiDOL is better than the others. This also indicates that broadcast storm problem did not effect our protocol due to its probabilistic density adaptive functions.

For understanding the behavior of EpiDOL under different conditions we added background traffic by sending FTP packets. When we send packets with 0.01 seconds frequency, this effects network clearly by decreasing the throughput. This showed that, unless the background traffic is heavy, EpiDOL is not significantly affected .

Including the range adaptivity feature to EpiDOL, we strengthened our algorithm. For providing trace independent adaptivity, we use CBR and reception rate as our decision parameters. Both of the statistic can be easily obtain without any additional requirements on the nodes. Despite to the changes in the packet generation rate, the highest throughput is achieved within a certain CBR range. Retaining CBR in this interval, by actively changing transmission range, increased the throughput and reliabitiy of the EpiDOL. Additionally by joint evaluation of CBR and reception rate ensure quick recovery from the cases with severe collisions. The last version of the adaptivity function improves throughput 25% in high densities while comparing with raw EpiDOL.

We designed and optimized EpiDOL for linear highway scenarios. As a future work, first we can consider more complicated and realistic highway structures including cross roads and curves etc. Then, we can further investigate the performance of the EpiDOL in urban environments and we can modify the proposed parameters accordingly. Eventually this two works can be combined as a whole by using adaptive parameters depend on the environment information acquired from the GPS system.

# References

[1] S. Biswas, R. Tatchikou, and F. Dion, "Vehicle-to-vehicle wireless communication protocols for enhancing highway traffic safety," *Communications Magazine, IEEE*, vol. 44, no. 1, pp. 74–82, Jan. 2006.

[2] F. Li and Y. Wang, "Routing in vehicular ad hoc networks: A survey," *Vehicular Technology Magazine, IEEE*, vol. 2, no. 2, pp. 12 –22, june 2007.

[3] O. Tonguz, N. Wisitpongphan, and F. Bai, "Dv-cast: A distributed vehicular broadcast protocol for vehicular ad hoc networks," *Wireless Communications, IEEE*, vol. 17, no. 2, pp. 47 –57, april 2010.

[4] M. Nekovee, "Epidemic algorithms for reliable and efficient information dissemination in vehicular ad hoc networks," *Intelligent Transport Systems, IET*, vol. 3, no. 2, pp. 104 –110, june 2009.

[5] R. Meireles, P. Steenkiste, and J. Barros, "Dazl: Density-aware zone-based packet forwarding in vehicular networks," in *Vehicular Networking Conference (VNC), 2012 IEEE*, pp. 234–241.

[6] (2003) Fleetnet project. [Online]. Available: http://www.neclab.eu/Projects/fleetnet.htm

[7] Cartel project. [Online]. Available: http://cartel.csail.mit.edu/doku.php

[8] O. Tonguz, N. Wisitpongphan, F. Bai, P. Mudalige, and V. Sadekar, "Broadcasting in vanet," in *2007 Mobile Networking for Vehicular Environments*, may, pp. 7 –12.

[9] N. Wisitpongphan, O. Tonguz, J. Parikh, P. Mudalige, F. Bai, and V. Sadekar, "Broadcast storm mitigation techniques in vehicular ad hoc networks," *Wireless Communications, IEEE*, vol. 14, no. 6, pp. 84 –94, december 2007.

[10] R. Schwartz, A. Ohazulike, C. Sommer, H. Scholten, F. Dressler, and P. Havinga, "Fair and adaptive data dissemination for traffic information systems," in *Vehicular Networking Conference (VNC), 2012 IEEE*, pp. 1–8.

[11] J. Blum, A. Eskandarian, and L. Hoffman, "Challenges of intervehicle ad hoc networks," *Intelligent Transportation Systems, IEEE Transactions on*, vol. 5, no. 4, pp. 347 – 351, dec. 2004.

[12] T. Taleb, M. Ochi, A. Jamalipour, N. Kato, and Y. Nemoto, "An efficient vehicle-heading based routing protocol for vanet networks," in *Wireless Communications and Networking Conference, 2006. WCNC 2006. IEEE*, vol. 4, april 2006, pp. 2199 –2204.

[13] T. Taleb, E. Sakhaee, A. Jamalipour, K. Hashimoto, N. Kato, and Y. Nemoto, "A stable routing protocol to support its services in vanet networks," *Vehicular Technology, IEEE Transactions on*, vol. 56, no. 6, pp. 3337 –3347, nov. 2007.

[14] P. Costa, D. Gavidia, B. Koldehofe, H. Miranda, M. Musolesi, and O. Riva, "When cars start gossiping," in *Proceedings of the 6th workshop on Middleware for network eccentric and mobile applications*, ser. MiNEMA '08, 2008, pp. 1–4.

[15] A. Vahdat and D. Becker, "Epidemic routing for partially-connected ad hoc networks," Tech. Rep., 2000.

[16] O. Ozkasap, Z. Genc, and E. Atsan, "Epidemic-based reliable and adaptive multicast for mobile ad hoc networks," *Comput. Netw.*, pp. 1409–1430.

[17] C. Barberis and G. Malnati, "Epidemic information diffusion in realistic vehicular network mobility scenarios," in *Ultra Modern Telecommunications Workshops, 2009. ICUMT '09. International Conference on*, oct., pp. 1 –8.

[18] V. Naumov, R. Baumann, and T. Gross, "An evaluation of inter-vehicle ad hoc networks based on realistic vehicular traces," in *Proceedings of the 7th ACM international symposium on Mobile ad hoc networking and computing*, ser. MobiHoc '06, 2006, pp. 108–119.

[19] J. Zuo, Y. Wang, Y. Liu, and Y. Zhang, "Performance evaluation of routing protocol in vanet with vehicle-node density," in *Wireless Communications Networking and Mobile Computing (WiCOM), 2010 6th International Conference on*, sept., pp. 1 –4.

[20] Z. J. Haas, J. Y. Halpern, and L. Li, "Gossip-based ad hoc routing," *IEEE/ACM Trans. Netw.*, vol. 14, no. 3, pp. 479–491.

[21] A. Xeros, M. Lestas, M. Andreou, and A. Pitsillides, "Adaptive probabilistic flooding for information hovering in vanets," in *Vehicular Networking Conference (VNC), 2010 IEEE*, pp. 239–246.

[22] A. M. Hanashi, A. Siddique, I. Awan, and M. Woodward, "Dynamic probabilistic flooding performance evaluation of on-demand routing protocols in manets," in *Proceedings of the 2008 International Conference on Complex, Intelligent and Software Intensive Systems*, ser. CISIS '08, pp. 200–204.

[23] H. AlHazza, "Enhancing dynamic probabilistic broadcasting flooding scheme in manets," in *Humanities, Science and Engineering (CHUSER), 2011 IEEE Colloquium on*, pp. 106–110.

[24] F. Nourazar and M. Sabaei, "Dapf: An efficient flooding algorithm for mobile ad-hoc networks," in *2009 International Conference on Signal Processing Systems*, pp. 594–598.

[25] J.-d. Abdulai, A. Mohammed, K. Nokoe, and E. Oyetunji, "Route discovery in wireless mobile ad hoc networks with adjusted probabilistic flooding," in *Adaptive Science Technology, 2009. ICAST 2009. 2nd International Conference on*, pp. 99–109.

[26] T. Tielert, D. Jiang, Q. Chen, L. Delgrossi, and H. Hartenstein, "Design methodology and evaluation of rate adaptation based congestion control for vehicle safety communications," in *Vehicular Networking Conference (VNC), 2011 IEEE*, pp. 116–123.

[27] L. Yang, J. Guo, and Y. Wu, "Channel adaptive one hop broadcasting for vanets," in *Intelligent Transportation Systems, 2008. ITSC 2008. 11th International IEEE Conference on*, pp. 369–374.

[28] H. Lu and C. Poellabauer, "Balancing broadcast reliability and transmission range in vanets," in *Vehicular Networking Conference (VNC), 2010 IEEE*, pp. 247–254.

[29] "Ieee standard for information technology– local and metropolitan area networks– specific requirements– part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications amendment 6: Wireless access in vehicular environments," *IEEE Std 802.11p-2010 (Amendment to IEEE Std 802.11-2007 as amended by IEEE Std 802.11k-2008, IEEE*

*Std 802.11r-2008, IEEE Std 802.11y-2008, IEEE Std 802.11n-2009, and IEEE Std 802.11w-2009)*, pp. 1–51, 15.

[30] Sumo - simulation of urban mobility. [Online]. Available: http://sumo.sourceforge.net

[31] Network simulator, ns-3. [Online]. Available: http://www.nsnam.org/

[32] M. Zhang and R. Wolff, “Routing protocols for vehicular ad hoc networks in rural areas,” *Communications Magazine, IEEE*, vol. 46, no. 11, pp. 126 –131, november 2008.