A Comparative Study of Data Dissemination Models for VANETs

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Abstract

VANETs (vehicular ad hoc networks) are emerging as a new network environment for intelligent transportation systems. Many of the applications built for VANETs will depend on the data push communication model, where information is disseminated to a group of cars. In this paper, we present a formal model of data dissemination in VANETs and study how VANET characteristics, specifically the bidirectional mobility on well defined paths, affects the performance of data dissemination. We study the data push model in the context of TrafficView, a system that we have implemented to disseminate information about the vehicles on the road. Traffic data could be disseminated using the cars moving on the same direction, cars moving in the opposite direction, or cars moving in both directions.

Our analysis as well as simulation results show that dissemination using only the cars in the opposite direction increases the data dissemination performance significantly.

1 Introduction

In the near future, the number of vehicles equipped with computing technologies and wireless communication devices, commonly referred as telematics, is poised to increase dramatically. For instance, it is predicted that the number of telematics subscribers in the United States will reach more than 15 million by 2009 [5]. Inter-Vehicle Communication is becoming a promising field of research and we are moving closer to the vision of intelligent transportation systems [3]. Such systems can enable a wide range of applications, such as collision avoidance, emergency message dissemination, dynamic route scheduling, and real-time traffic condition monitoring. Traditional vehicular networks for reporting accidents or traffic conditions rely on certain infrastructures, such as road-side traffic sensors reporting data to a central database, or cellular wireless communication between vehicles and a monitoring center. Users can query the aggregated information from a central database via cellular networks. The problem with such solutions is that they require expensive infrastructures installed on every road in which the system is going to be used. Additionally, they are not scalable owing to their centralized design.

Vehicular Ad-hoc Networks (VANETs) are emerging as the prefered network design for intelligent transportation systems. VANETs are based on short-range wireless communication (e.g., IEEE 802.11) between vehicles. The Federal Communications Commission (FCC) has recently allocated 75 MHz in the 5.9 GHz band for licensed Dedicated Short Range Communication (DSRC) [4] aimed at enhancing bandwidth and reducing latency for vehicle-to-vehicle and vehicle-to-infrastructure communication. The adoption of the DSRC spectrum for vehicle-to-vehicle communication is an indication of the increasing interest and expectations from this emerging technology.

Unlike infrastructure-based networks (e.g., cellular networks), these networks are constructed on-the-fly and do not require any investment besides the wireless network interfaces which will be a standard feature in the next generation of vehicles. Furthermore, VANETs enable a new class of applications that require time-critical responses (less than 50 ms) or very high data transfer rates (6-54 Mbps).

An important problem that has to be solved in VANETs is how to exchange traffic information among vehicles in a scalable fashion. In some applications information is disseminated proactively using broadcast (push model), while in others the information is obtained on-demand (pull model). It is believed that broadcast-based applications have the potential of bootstrapping vehicular ad-hoc networks. For this reason, in this paper, we focus on the data push communication model in VANETs.

The goal of the data push communication model is to exchange information (e.g., position, speed) among a set of moving vehicles in order to enable each individual vehicle to view and assess traffic conditions in front of it. Two main mechanisms could be used to achieve this goal: *flooding* and *dissemination*. In the *flooding* mechanism, each individual vehicle periodically broadcasts information about itself. Every time a vehicle receives a broadcast message, it stores it and *immediately* forwards it by re-broadcasting the message. This mechanism is clearly not scalable due to the large number of messages flooded over the network, especially in high traffic density scenarios.

In the *dissemination* mechanism, each vehicle broadcasts information about itself *and* the other vehicles it knows about. Each time a vehicle receives information broadcasted by another vehicle, it updates its stored information accordingly, and defers forwarding the information to the next broadcast period, at which time it broadcasts its updated information. The dissemination mechanism is scalable, since the number of broadcast messages is limited, and they do not flood the network.

The dissemination mechanism can either broadcast information to vehicles in all directions, or perform a directed broadcast restricting information about a vehicle to vehicles behind it. Further, the communication could be relayed using only the vehicles travelling in the direction of the vehicle, vehicles travelling in other direction, or vehicles travelling in both directions. To decide which is the best dissemination model, however, a formal model for data dissemination in VANET that considers multiple traffic parameters is required.

This paper presents a formal model of data dissemination in VANET and analyzes how VANET characteristics, mainly the bidirectional mobility on well defined paths, affect the performance of data dissemination. We evaluate, by means of simulation, three data dissemination models: $same-dir$, $opp-dir$, and $bi-dir$ in the context of TrafficView [21, 10], a system for scalable traffic data dissemination and visualization in VANETs. Contrary to our expectations that using vehicles moving in both directions will yield the best performance, our analysis as well as simulation results show that dissemination using only the cars in the opposite direction increases the data dissemination performance in TrafficView significantly.

The rest of this paper is organized as follows. In section 2 we describe the TrafficView system and its prototype. Section 3 describes our formal model for data dissemination over VANET. Section 4 shows the simulation results and the lessons learned from these results. Related work is discussed in Section 5. The paper concludes in Section 6.

2 TrafficView

TrafficView is a system for traffic data dissemination and visualization in vehicular ad-hoc networks. The goal of TrafficView is to provide continuous updates to each vehicle about traffic conditions, which can assist the driver in route planning as well as driving in adverse weather conditions when visibility is low.

2.1 TrafficView Overview

Each participating vehicle in the TrafficView system is equipped with a computing device, a short-range wireless interface and a GPS receiver. Optionally, an on-board diagnostics system (OBD) interface [2] can be used to acquire mechanical and electrical data from sensors installed in vehicles. The GPS receiver provides location, speed, current time and direction of the vehicle. Each participating vehicle gathers and broadcasts information about itself and other vehicles, in a peer-to-peer fashion. The display shows a map annotated with real-time traffic conditions on different roads as well as dynamic information about other cars, such as their location.

Each vehicle stores information about itself and other vehicles in a local database. The records in this database are periodically broadcasted. A record consists of the vehicle identification, position in the form of latitude and longitude, current speed of the vehicle, direction, and timestamps corresponding to when this record was first created and when this record was received.

In TrafficView, we have chosen to broadcast all data stored at a vehicle in a single packet. This simple data propagation model has three advantages: (1) it limits the bandwidth consumed by each vehicle, (2) it limits the number of re-transmissions due to collisions, and (3) it avoids dealing with flow control (which would be necessary if data would be split in multiple packets). The data stored at a vehicle is usually greater than the size of a packet. Therefore, data aggregation techniques are applied to the records exchanged.

Data aggregation is based on the semantics of the data. For example, the records about two vehicles can be replaced by a single record with little error, if the vehicles are very close to each other and move with relatively the same speed. For the aggregation mechanism, we used the *ratio-based* mechanism. In such mechanism, the road in front of the vehicle is divided to a number of regions ($1 \leq i \leq n$). For each region, an aggregation ratio (a_i) is assigned. The aggregation ratio is defined as the inverse of the number of individual records that would be aggregated in a single record. Each region is assigned a portion (p_i where $0 < p_i \leq 1$) of the remaining free space in the broadcast message. The aggregation ratios and region portion values are assigned according to the importance of the regions and how accurate the broadcast information about the vehicles in that region is needed to be.

2.2 TrafficView Prototype

We have developed a working prototype of TrafficView which has been installed in vehicles and tested by driving outdoors under realistic traffic conditions. We have evaluated our prototype by means of extensive experiments performed by driving three cars fitted with TrafficView system in a highway environment. In the process of our outdoor experimentation, we have learned valuable lessons about the kind of challenges that can hinder development and deployment of simple vehicular applications.

The prototype of TrafficView was implemented mostly in Java with portions in C and the implementation has

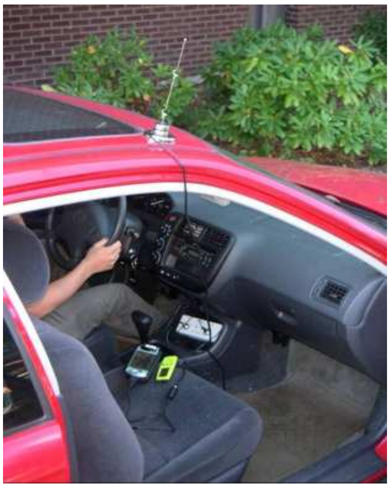

Figure 1. TrafficView Prototype Installed in a Car

been ported to both Windows and Linux. OpenGL was adopted for graphical display. The User Interface (UI) is composed of two panels: *NearView* and *MapView*. The NearView panel only displays cars on the same road. Cars are displayed in 3D as colored rectangular blocks. The MapView displays the map of the region annotated with information about cars. The roads are shaded based on traffic density. We used publicly available Tiger Database maps. In order to deal with GPS inaccuracy, we implemented an algorithm that uses angles between roads and speed of the car to accurately determine its position. Figure 1 presents the TrafficView prototype installed in a car. As the picture shows, we have also attached an antenna to the 802.11b card. During our initial real-life traffic experiments on the roads, we realized that having the wireless cards inside the cars decreases the communication range significantly. Therefore, we have attached omni-directional antennas which increase the communication range to up to 300 meters. On the other hand, we have observed that the speed does not influence the communication significantly.

A fundamental limitation of outdoor experimentation is that we can only test the system using a limited number of cars. Unless there is a widespread adoption of the system, it becomes essential to build a simulation environment to test the system in the presence of a large number of cars. With this in mind, we have implemented the TrafficView system in ns-2 simulator with the objective being to compare the performance of the system in the presence of a large number of cars. Different aggregation algorithms have been evaluated and compared using this simulation environment [21]. This paper uses the TrafficView simulation environment to compare the efficiency of different data dissemination models.

3 Analysis of Data Dissemination in TrafficView

In this section we analyze different dissemination mechanisms.

3.1 Model Assumptions

In the following subsections, we assume that vehicles move on bidirectional roads, e.g., highways, where each direction consists of multiple lanes as shown in Figure 2. We assume the movement direction to be either $Right$ as shown on the road in the lower part of Figure 2 (e.g., v_{1R} and v_{2R} shown in the figure), or $Left$ on the road in the upper part of the figure (e.g., v_{1L} and v_{2L} shown in the figure). The Vehicles' average speeds are S_R and S_L for $Right$ and $Left$ directions respectively. We assume vehicles are equipped with position systems (e.g, GPS) and wireless devices and external antenna for communication. All transmissions are omni-directional and with communication range R[1].

In TrafficView, each vehicle is concerned about the road information ahead of it on its direction. In order to maintain this, vehicles and road information should be propagated backwards with respect to their moving direction (i.e., propagated in the opposite direction). We assume vehicles broadcast data packet every B seconds. With no loss of generality and for the sake of simplicity, we only focus here on propagating information about vehicles moving in the $Right$ direction in which information should propagate from right to left.

3.2 Dissemination Models

We differentiate between two types of broadcasted data: *generated data* and *relayed data*. Generated data, shown as small red circles in Figure 2, is the vehicle's data (e.g., ID, speed, and location), while relayed data, shown as the large yellow circle, is the data stored locally about other vehicles ahead. Originally, TrafficView model described in Section 2 broadcasts both the generated and the relayed data in every broadcast packet.

In this paper, we compare between three main dissemination/propagation models: *same-dir*, *opp-dir*, and *bi-dir*. In *same-dir*, which is the original TrafficView model, each vehicle broadcasts both its generated data and the relayed data in a single packet. This broadcasted information propagates only through vehicles moving in the *same* direction. Therefore, a vehicle drops any received packet broadcasted by another vehicle on the same road behind it. More specifically, when a vehicle v_1 broadcasts a data packet; vehicle v_2 will accept this packet if and only if:

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[1] In practice, the transmission range could reach about 60 meters. However, using external antenna extends the transmission range to 300 meters.

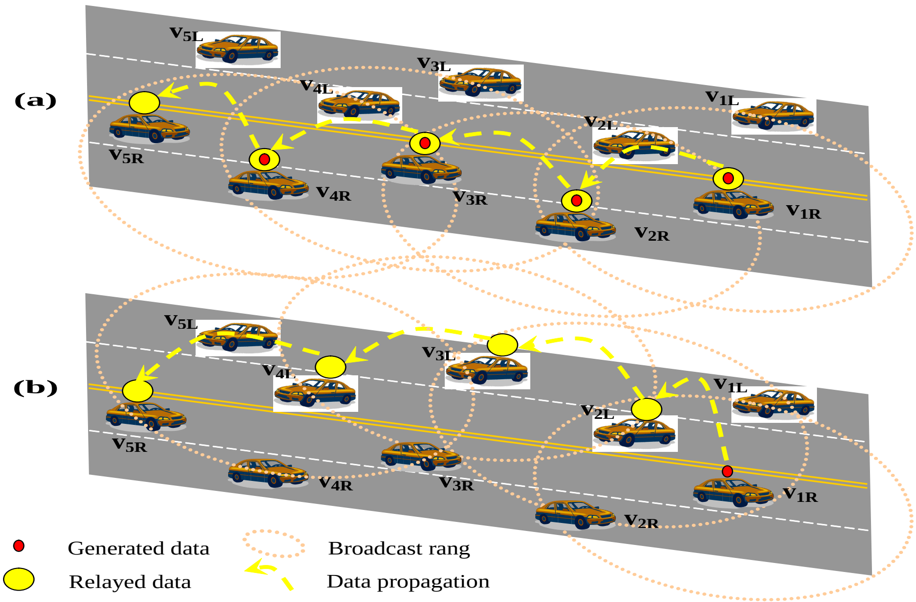

Figure 2. Dissemination models: (a) the *same-dir* dissemination model, and (b) the *opp-dir* dissemination model

1. v_2 is within the transmission range of v_1, and
2. v_1 and v_2 are moving in the same direction, and
3. v_1 is in front of v_2 with respect to their movements.

Figure 2(a) shows how information is propagated from vehicle v_{1R} to vehicle v_{5R} in the $Right$ direction using *same-dir* model. Note that no vehicle from the opposite direction participates in this model.

On the other hand, in *opp-dir* model, vehicles in *same* direction (e.g., $Right$) only broadcast the generated data. These generated data are accumulated and propagated backwards by the vehicles in the *opposite* direction (e.g., $Left$). When vehicle v_1 broadcasts a packet, v_2 which is within the transmission range of v_1 will handle the received packet as follow:

1. If v_1 and v_2 are moving $Right$, v_2 will accept the packet if v_1 is in front of v_2. This is the case when v_1 broadcasts its generated data.
2. If v_1 and v_2 are moving $Left$, v_2 will accept the packet if v_2 is in front of v_1. This is the case when v_1 relays a packet.
3. If v_1 is moving $Right$ and v_2 is moving $Left$, v_2 will accept the packet regardless of the relative position of the vehicles.

Figure 2(b) shows how information is propagated from vehicle v_{1R} to vehicle v_{5R} using *opp-dir* model. The *bi-dir* model combines both *same-dir* and *opp-dir* models.

3.3 Analysis of Dissemination Models

Two main definitions we will use through this section: *latency time* and *broadcast utilization*. Latency time (L) is defined as the time needed to propagate generated data from the vehicle to another vehicle at D meters away from it. Broadcast utilization U is defined as the percentage of the area covered by the transmission range of the current broadcast that was not covered by the transmission range of the previous broadcast of the same packet. Since the transmission range of a packet is much larger than the lane's width and consequently the road's width, we measure broadcast utilization by the transmission range along the road only, assuming the same transmission range across all the lanes.

Due to space constraint, we limit the analysis in this section to the broadcast utilization in *same-dir* and *opp-dir* models. We have the following propositions:

Proposition 3.1 *The broadcast utilization of* same-dir *model is* 25%.

Proposition 3.2 *The broadcast utilization for the* generated data *in* opp-dir *model is given by:*

$$U = 100 * \begin{cases} 0.25 & \text{if } \hat{S}B \leq \frac{R}{2} \\ \frac{\hat{S}B}{2R} & \text{if } \frac{R}{2} \leq \hat{S}B \leq R \\ \frac{6\hat{S}BR - R^2 - (\hat{S}B)^2}{8R^2} & \text{if } \hat{S}B > R \end{cases}$$

where $\hat{S} = (S_R + S_L)$.

Proposition 3.3 *The broadcast utilization for the* relayed data *in* opp-dir *model is given by:*

$$U = 100 * \begin{cases} \frac{R+2\hat{S}B}{4R} & \text{if } \hat{S}B \leq R \\ \frac{4\hat{S}BR-(\hat{S}B)^2}{4R^2} & \text{if } \hat{S}B > R \end{cases}$$

where $\hat{S} = (S_R + S_L)$.

Due to space constraints, we show only the proof of Proposition 3.2.

Proof In Figure 3(a), vehicle v_{1R} broadcasts its generated data at time t. Assume vehicle v_{1L} hears this broadcast and is x meters away from v_{1R} where x can have values from the range $[-R, R]$. After a broadcast period B, vehicle v_{1L} would relatively move an average distance of $\hat{S}B$ and it reaches position $x + \hat{S}B$ with respect to v_{1R} where $\hat{S} = (S_R + S_L)$. At the next broadcast period, v_{1L} will cover area extending to $R + x + \hat{S}B$. Since the previous broadcast of v_{1R} covers only till range R and since the maximum value of broadcast utilization is $2R$, the broadcast utilization of v_{1L} becomes: $U = \frac{min(x+\hat{S}B,2R)}{2R} * 100$. By averaging over x, we get the average broadcast utilization as follow:

$$\begin{aligned} U &= \frac{\int_{-R}^{R} U dx}{2R} \\ &= 100 * \frac{\int_{-R}^{R} min(x+\hat{S}B, 2R)dx}{4R^2} \\ &= 100 * \begin{cases} \frac{\int_{-R}^{R} (x+\hat{S}B)dx}{4R^2} & \text{if } \hat{S}B \leq R \\ \frac{\int_{-R}^{2R-\hat{S}B} (x+\hat{S}B)dx}{4R^2} & \\ \quad + \frac{\int_{2R-\hat{S}B}^{R} (2R)dx}{4R^2} & \text{if } \hat{S}B > R \end{cases} \\ &= 100 * \begin{cases} \frac{\hat{S}B}{2R} & \text{if } \hat{S}B \leq R \\ \frac{6\hat{S}BR-R^2-(\hat{S}B)^2}{8R^2} & \text{if } \hat{S}B > R \quad \blacksquare \end{cases} \end{aligned}$$

Figure 4 shows the broadcast utilizations for *same-dir* and *opp-dir* models. Note that in *opp-dir*, if we increase the lower bound range ($-R$) in the above analysis to higher value, we can increase the utilization by limiting the broadcast to vehicles with larger new coverage areas.

4 Evaluation

In this section we studied the performance of the dissemination models *same-dir*, *opp-dir*, and *bi-dir* in large scale networks by means of *ns-2* simulator [24]. Different scenarios were considered to test the models.

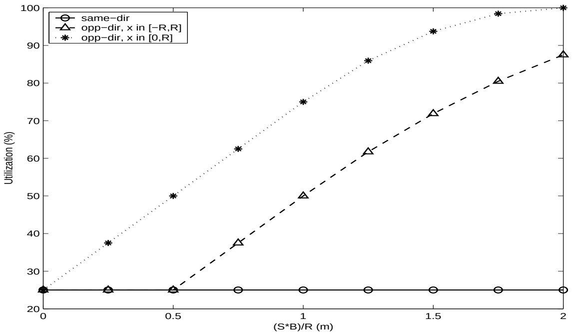

Figure 4. Broadcast utilization for different dissemination models

4.1 Simulation Results

In this paper we make use of the traffic generator tool we developed [21, 22, 10]. The scenario generator accepts as parameters the simulation time, road length in meters, number of lanes per road, average speed of the vehicles in meters/sec, average gap distance between vehicles on same lane, and the number of vehicles on the road.

For all the simulations in this paper, we fixed the length of the road to be 15,000 meters with 3 lanes on each side. We used 802.11b (with a data transmission rate of 11Mb) as the wireless media with a transmission range of 250m. During a simulation, nodes broadcast messages periodically. The broadcast period is selected uniformly from $[1.75, 2.25]$ seconds, and each node recalculates the next broadcast period after the current broadcast. For all the simulation runs, we use broadcast messages of size 2312 (the maximum payload size of 802.11b standards) and we fix the simulation time to 300 seconds.

4.1.1 Metrics

In this simulation we will study the data propagation for vehicles on one side of the road. In doing this, vehicle moving right will generate and propagate data while vehicles moving left are used only in propagating data. All the metrics in this section are measured for the vehicles moving right. To evaluate the performance of our propagation models we consider the following metrics:

- *Accuracy*: The road in front of each vehicle is divided into regions of 500 meters length, and the average error in estimating the position of vehicles in each region is calculated. In the accuracy graphs, the average estimation error for each region is shown, averaged over all the nodes during the simulation.

- *Knowledge Percentage*: The road in front of each vehicle is divided into regions of 200 meters long.

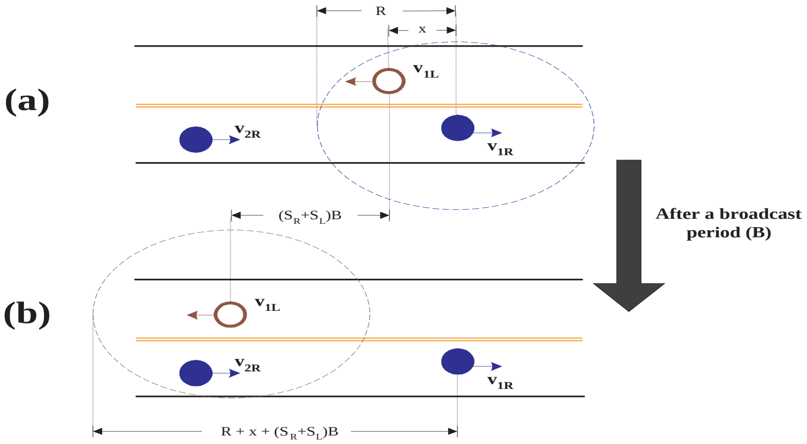

Figure 3. Dissemination of *generated data* **in** *opp-dir***.**

For each region, the percentage of the vehicles in that region about which the current node knows, is defined as the knowledge percentage of that node for that region. The knowledge percentage graph presents the knowledge percentage for each region, averaged over all the nodes during a simulation run.

- *Latency Time*: This metric measures the elapsed time between the time at which a vehicle's information is generated and time at which it is received by another vehicle. Similar to accuracy metric, the road in front of each vehicle is divided into regions of 500 meters length, and the latency time to receive the information of vehicles in each region is calculated.

- *Utilization rate*: This metric approximates the broadcast utilization rate described in Section 3. When a vehicle receives a packet, some of the information would not be useful because either they are about cars behind or they are outdated information. Utilization rate of vehicle measures the average percentage of the useful vehicle information contained in received packets by this vehicle. This metric measures the average percentage over all the vehicles in the simulation.

4.1.2 Results

We experimented with different scenario parameters such as vehicle densities, vehicle speed, and broadcast rate. We also switched between the propagation model where no aggregation mechanism is used and the model in the presence of an aggregation mechanism. However, due to space limitation we limit the results here to the experiments with different vehicle densities in which the aggregation mechanism is used. For further details about the other experiments, please refer to our technical report [23].

To study the effects of vehicle density, we fixed the average speed of vehicles to 30m/s and the average periodic broadcast to 2 seconds. We changed the average gap between each consecutive car from 100m (dense traffic) to 500m (regular traffic) to 1000m (sparse traffic).

Figure 5 shows the knowledge percentage graphs for *same-dir*, *opp-dir*, *bi-dir* models. As shown, the *opp-dir* and *bi-dir* models have better knowledge than the *same-dir* model. Although *bi-dir* shows better knowledge than *opp-dir*, Figure 6 shows that such knowledge has higher errors. For example, for the 500m gap scenario, the average error for *same-dir* at distance of 4750m is about 300m. However, using *opp-dir* reduced such error to 200m only (30% reduction) while *bi-dir* increases this error to 380m (90% higher than the *opp-dir* error). The explanation resides in the following: 1) in *bi-dir* model data propagates faster on the opposite direction than the current direction due to the effect of the mobility speed on the data propagation, and since aggregation looses some of the vehicles information such as the original time of generating data, vehicles may overwrite the current information by outdated information since it can't recognize it is outdated, and 2) although a vehicle may purge some information because of the aging mechanism, *bi-dir* mechanism will reinsert purged old data and this increases the average error. Please refer to [22] for further details on aggregation and aging mechanisms.

Figure 7 confirms the previous observations in which *bi-dir* model has higher latency than *opp-dir* model which indicates that the vehicle's information received through data propagation in the same direction is received later than the propagation through the opposite direction. From those figures, we can see that the difference between *opp-dir* and *bi-dir* models is signified with the increase of the gap distance because the relative propagation speed between the opposite direction and the same direction increases with the gap distance. Figure 8 shows the utilization rate for the three models. As expected, the utilization rate increases with the gap distance and *opp-dir* has the highest utilization

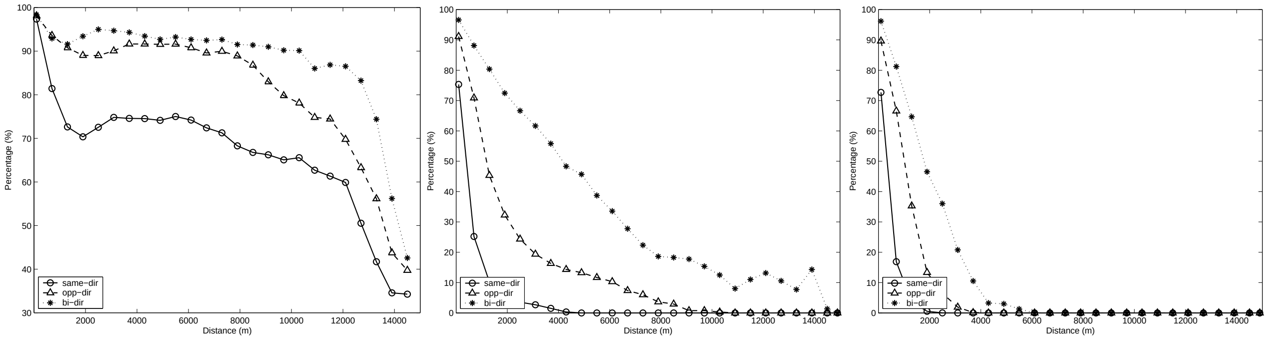

Figure 5. Knowledge graph: (a)Gap=100m, (b)Gap=500m, (c)Gap=1000m

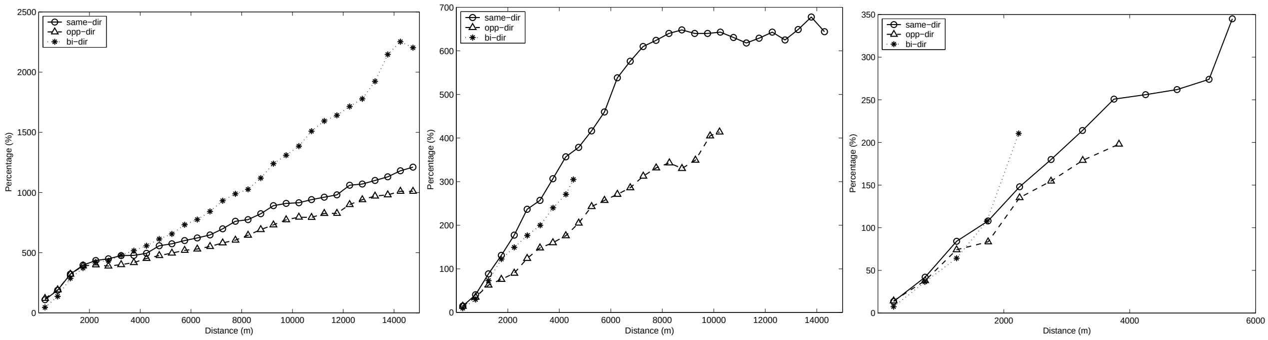

Figure 6. Error graph: (a)Gap=100m, (b)Gap=500m, (c)Gap=1000m

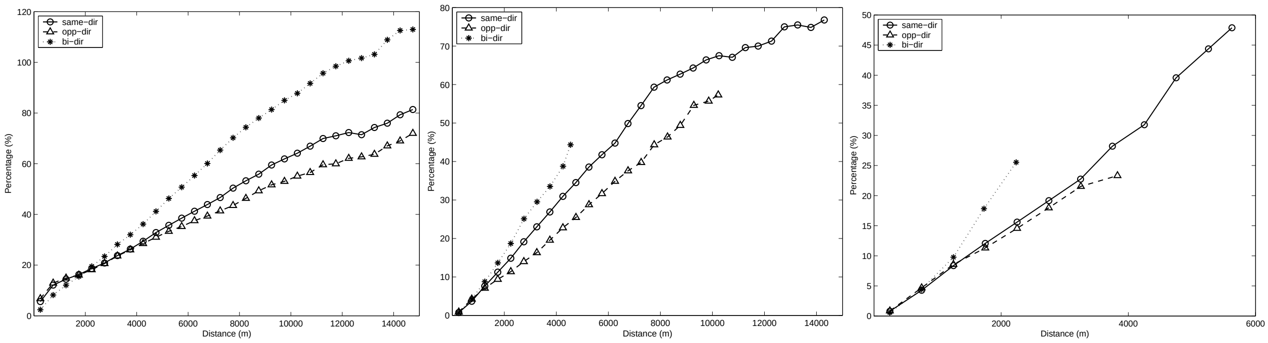

Figure 7. Latency graph: (a)Gap=100m, (b)Gap=500m, (c)Gap=1000m

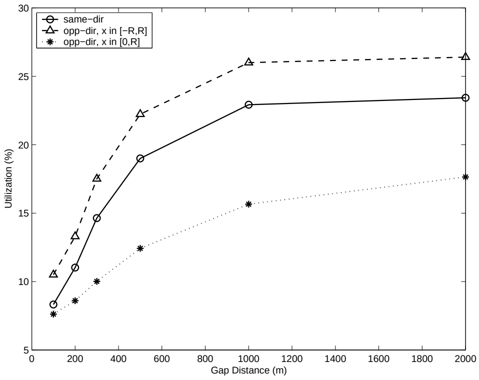

Figure 8. Broadcast Utilization for different dissemination models (Simulation results)

rate among all models.

We observed similar behavior when we experimented with other parameters such as vehicle speed and broadcast rate. From the above results we conclude that *opp-dir* model is more efficient than *bi-dir* model in terms of average error, latency, and network utilization. This indicates that the data dissemination model employed by *opp-dir* model is more efficient and scalable than the *same-dir* and *bi-dir* models.

5 Related Work

Several research groups have explored the idea of data dissemination using short-range Vehicle-to-Vehicle communication. Flooding is the most common approach for broadcasting without explicit neighbor information in MANETS. [26] shows that flooding results in severe performance degradation, especially with high node density, as a result of the broadcast storm problem. [17] proposes a way to improve flooding thereby avoiding the broadcast storm. However this mechanism requires knowledge about a node's neighbors and the network topology.

Several forwarding-based protocols for data dissemination have been proposed. An opportunistic forwarding approach is proposed in [7]. [25] proposes a trajectory-based forwarding scheme. [31] uses a combination of opportunistic forwarding and a trajectory-based approach while specifically addressing vehicle mobility. Forwarding, however, is more suited for applications with reliable delivery requirements than for latency-sensitive safety message dissemination. In the latter case, broadcast is the preferred message dissemination mechanism.

A number of systems have been designed specifically with traffic safety applications in mind [18, 8]. [32] studies safety applications in the context of DSRC. All these systems make use of simple directed broadcast-based communication without considering the efficiency of the data dissemination mode. [14] improves efficiency in multi-hop broadcast by addressing broadcast storm, hidden node, and reliability problems. However this protocol performs simple directed broadcast and is lane-agnostic.

To the best of our knowledge, ours is the first study that presents a formal model of data dissemination in VANETs and studies how performance of data dissemination is affected by bidirectional mobility on well-defined paths.

6 Conclusions and Future Work

In this paper we presented a formal model of data dissemination in VANETs and how the performance of data dissemination is affected by bi-directional lane mobility. Three models of data dissemination are compared in the context of their performance over the TrafficView system. We show, by means of analysis and simulations, that the data dissemination model that uses only vehicles in the opposite direction for propogating data shows best performance.

In this paper, we assume that traffic conditions such as density of vehicles in the two opposite directions are similar. In reality, this would often not be the case. We plan to study the performance of the different dissemination models under such different conditions.

In our current system, all cars participate in broadcasting. Our analysis shows that broadcast by a subsection of cars is enough to achieve a good utilization. As future work, we are working on the selection criteria that decides whether a car should participate in broadcasting or not. This criteria will depend on several factors such as traffic density and car speeds.

Simulation-based methodologies such as ns-2 use a networking model that is a simplified version of real-life networking. Emulation-based approaches offer interesting tradeoffs between pure simulation and full-scale experiments with acceptable levels of realism and reproducibility [27]. Our future work consists of evaluating the TrafficView system using a wireless grid emulation environment.

We are also investigating several other traffic applications that can benefit from the use of the TrafficView dissemination mode.

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