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 vehicles. 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 we have implemented to disseminate information about the vehicles on the road. Traffic data could be disseminated using vehicles moving on the same direction, vehicles moving in the opposite direction, or vehicles moving in both directions. Our analysis as well as simulation results show that dissemination using only vehicles 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 [9]. 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 infrastructure, such as road-side traffic sensors reporting data to a central database, or cellular wireless communication between vehicles and a monitoring center. The problem with these systems is that they require expensive infrastructure to be 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 preferred 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), VANETs are constructed on-the-fly and do not require any investment besides the wireless network interfaces that 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 other applications obtain information using 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) on regular basis among a set of moving vehicles in order to enable each individual vehicle to view and assess traffic conditions ahead 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

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clearly not scalable due to the large number of messages flooded over the network, especially in high traffic density scenarios. On the other hand, each vehicle, in the *dissemination* mechanism, 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 vehicles traveling in the same direction, vehicles traveling in the opposite direction, or vehicles traveling in both directions. In this paper, we present a formal model of data dissemination in VANETs and analyze 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 [27, 15], 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 vehicles 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 present an overview of 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 vehicles about traffic conditions, which can assist the driver in route planning as well as driving in adverse weather conditions when visibility is low [27, 15].

2.1 TrafficView Overview

A participating vehicle in TrafficView 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. The vehicle gathers and broadcasts information about itself and the other vehicles, in a peer-to-peer fashion. Gathered information is stored in local database records. 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 the time this record was first created and the time this record was received. An LCD touch-screen display fitted on the vehicle shows a map annotated with real-time traffic conditions on different roads as well as dynamic information about other vehicles, such as their location.

In TrafficView, we have chosen to periodically broadcast all stored data in a vehicle within a single packet. This simple scheme 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. Since the data stored at a vehicle is usually greater than the size of a packet, data aggregation techniques are applied.

Data aggregation is based on the semantics of the data. For example, records about two vehicles can be replaced by a single record with limited error if vehicles are very close to each other and relatively move with similar speeds. For the aggregation mechanism, we use *ratio-based* mechanism [27]. In such a mechanism, the road in front of a vehicle is divided into 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.

In TrafficView the relative positions of vehicles is computed, using stored road maps, by mapping the vehicle's latitude and longitude coordinates to points on the road in which the vehicle is driving. Using the relative positions of vehicles allows TrafficView to work in all kinds of road topologies like a *zigzag* mountain road. We create the road map of a region by making use of the data files offered by the US Census Bureau through the 2005 Tiger Line database [7]. This database provides a set of latitude and longitude points corresponding to every road for every county in each state of the US [8]. The algorithm to calculate a vehicle's position in the map based on its latitude and longitude is explained in detail in our earlier work [15].

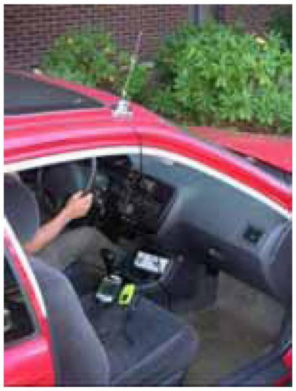

Figure 1. TrafficView prototype installed in a vehicle

Figure 2. Outdoor experiment of the TrafficView prototype

2.2 TrafficView Prototype

A working prototype of TrafficView has been developed at Laboratory for Network-Centric Computing (DisCo Lab), Rutgers University [5]. This prototype was implemented mostly in Java with portions in C and the implementation has 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 vehicles on the same road. Vehicles are displayed in 3D as colored rectangular blocks. The MapView displays the map of the region annotated with information about vehicles. The roads are shaded based on traffic density. In order to deal with GPS inaccuracy, we implemented an algorithm that uses angles between roads and speed of the vehicle to accurately determine its position [15]. Figure 1 presents the TrafficView prototype installed in a vehicle. Omni-directional antennas are used to increase the communication range up to 300 meters.

We have evaluated our prototype by means of driving vehicles fitted with TrafficView in real traffic conditions. A driver can see the vehicles ahead of oneself using the TrafficView display component. The display consists of a first-person perspective view with visible vehicles as correspondingly colored 3D rectangles. Alternately, the driver can switch to a topological map view with roads colored according to traffic density. Additionally, drivers are warned of incidents like a vehicle in front pressing brakes by means of coloring the vehicle red. Figure 2 shows an outdoor experiment of the TrafficView prototype with three vehicles driving around the Rutgers campus. The LCD screen of the vehicle in the back shows the view of the road and the vehicles ahead of it.

Performance of data dissemination is crucial for systems such as TrafficView, which adopt data push communication model . Different data dissemination models have been developed for TrafficView prototype. Due to the limitations of the outdoor experiments in testing with large number of vehicles for logistical/practical reasons, we have implemented TrafficView in ns-2 simulator to be able to study performance of the system in the presence of a large number of vehicles. Different aggregation algorithms have been evaluated and compared using this simulation environment [27]. In this paper, we evaluate different data dissemination models using the developed TrafficView simulation environment under large scale scenarios.

3 Data Dissemination in TrafficView

In this section we define and analyze different dissemination models.

3.1 Model Assumptions

As described in the previous section, each vehicle in TrafficView computes the on-road relative position of other vehicles along the road it is moving on, regardless of the road topology. Therefore and without loss of generality, we assume vehicles move on bidirectional straight roads with multiple lanes in each direction as shown in Figure 3.

We assume the moving direction of a vehicle on the road is either to the $East$ as shown in the lower part of the road in Figure 3 (e.g., v_{1E} and v_{2E}), or to the $West$ as in the upper part of the road (e.g., v_{1W} and v_{2W} in Figure 3). The average speeds are S_E and S_W for $East$ and $West$ directions respectively. All transmissions are omni-directional and with communication range R.

Each vehicle in TrafficView is concerned about obtaining the road information ahead of it. In order to accomplish this, information should propagate backward with respect to the vehicle's direction (i.e., propagate in the opposite direction). We assume vehicles broadcast data packets periodically every B seconds. For the sake of simplicity, we only consider the propagation of information about vehicles

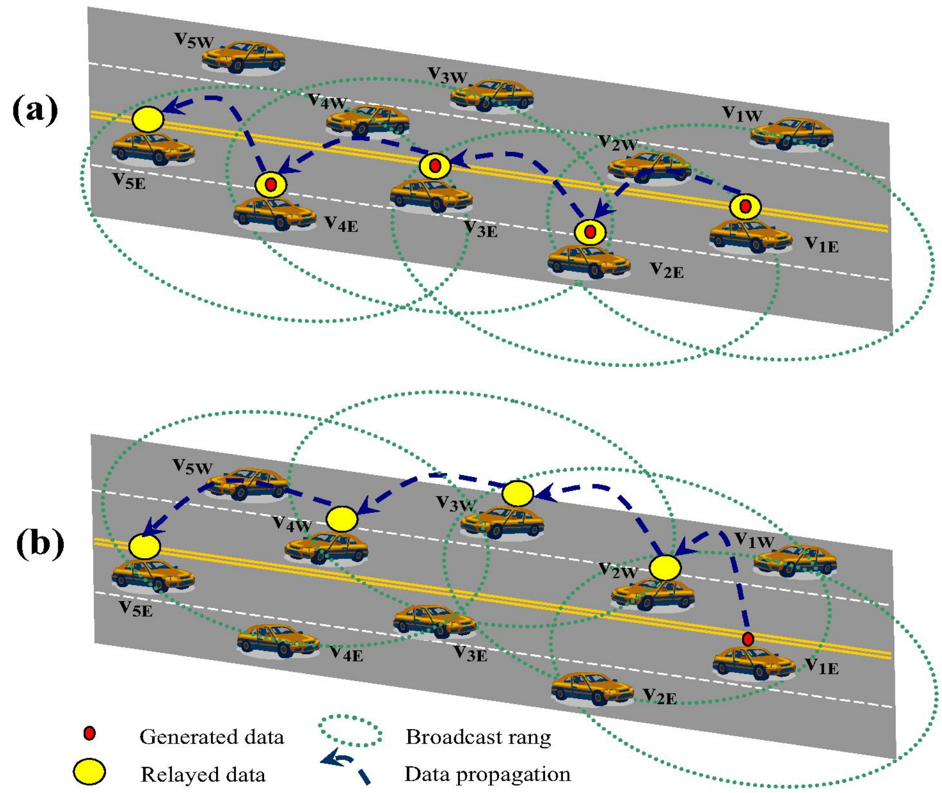

Figure 3. Dissemination models: (a) the same-dir dissemination model, and (b) the opp-dir dissemination model

moving $East$, so the direction of propagation is from the east to the west in the rest of the paper.

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 3, is the vehicle's own data (e.g., ID, speed, and location) that is updated every broadcast period. On the other hand, relayed data, shown as the large yellow circle, is the stored data about the other vehicles ahead and it is propagated backward with every broadcast period.

We compare three dissemination/propagation models: *same-dir*, *opp-dir*, and *bi-dir*. In the *same-dir* model, which is the original TrafficView model, each vehicle periodically broadcasts both its generated data and the relayed data (i.e., stored data) in the same data packet. When a vehicle broadcasts a data packet, only vehicles moving in the *same* direction are responsible for the propagation of this packet. More specifically, when a vehicle v_1 broadcasts a data packet; vehicle v_2 will accept this packet and propagate it later if and only if:

1. v_2 is within the transmission range of v_1, and
2. v_1 and v_2 are moving in the same direction (i.e., $East$), and
3. v_1 is in front of v_2 with respect to their directions (i.e., v_1 is located east of v_2).

Figure 3(a) shows how information is propagated from vehicle v_{1E} to vehicle v_{5E}, both moving $East$, using the *same-dir* model. Note that no vehicle from the opposite direction participates in this model.

On the other hand, generated and relayed data are not broadcasted together in the *opp-dir* model. Instead, vehicles in *same* direction (i.e., $East$) only broadcast their generated data. These generated data are aggregated and propagated backwards by the vehicles in the *opposite* direction (i.e., $West$). When vehicle v_1 broadcasts a packet (i.e., generated data when moving $East$, or relayed data when moving $West$); v_2 will handle the reception of this packet, giving that it is within the the transmission range of v_1, as follow:

1. If v_1 and v_2 are moving $East$, v_2 will accept the packet if v_1 is located east of v_2. This is the case when v_1 broadcasts its generated data.
2. If v_1 and v_2 are moving $West$, v_2 will accept the packet if v_2 is located west of v_1. This is the case when v_1 relays a packet.
3. If v_1 is moving $East$ (or $West$) and v_2 is moving $West$ (or $East$), v_2 will accept the packet regardless of the relative position of the vehicles.

Note that the first rule guarantees a fast delivery of the newly generated data to all the vehicles within one hop of the source vehicle. Figure 3(b) shows how information is propagated from vehicle v_{1E} to vehicle v_{5E} using the *opp-dir* model.

The *bi-dir* model combines both the *same-dir* and the *opp-dir* models. In this model, generated and relayed data are propagated by vehicles in the *same* direction (i.e., $East$) while vehicles in the *opposite* direction (i.e., $West$) only propagate relayed data. Unlike the other mechanisms, information in the *bi-dir* model is propagated by vehicles moving in both the *same* and the *opposite* directions.

3.3 Analysis of Dissemination Models

We evaluate the dissemination models using two metrics: *latency time* and *broadcast utilization*. Latency time (L) is defined as the time needed to propagate generated data between two vehicles positioned D meters from each other. Broadcast utilization U is defined as the percentage of the newly covered area by the current broadcast, which is not covered by any previous broadcast of the same data, to the total area covered by a broadcast. Since the transmission range is much larger than the lane width and consequently the road width, we compute broadcast utilization using only the transmission range along the road.

Due to the space constraint, we limit the analysis in this section to the broadcast utilization only. Given $\hat{S} = (S_E + S_W)$, we have the following propositions:

Proposition 3.1 *The average broadcast utilization of* generated and relayed data *in the* same-dir *model is* 25%.

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

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

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

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

Proposition 3.4 *The average broadcast utilization for the* bi-dir *model is half the average broadcast utilization of the* opp-dir *model for both* generated and relayed data.

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

Proof Consider Figure 4(a) where vehicle v_{1E} broadcasts its generated data at time t. Assume vehicle v_{1W} that receives this broadcast is x meters away from v_{1E} where the value of x is in the range $[-R, R]$. After a time period B, vehicle v_{1W} would relatively move an average distance of $\hat{S}B$ meters and becomes $x + \hat{S}B$ meters away from v_{1E} where $\hat{S} = (S_E + S_W)$. Therefore, at the next broadcast period, the broadcast of v_{1W} covers up to $R + x + \hat{S}B$ meters from v_{1E} as shown in Figure 4(a). Since the previous broadcast of same data by v_{1E} covers only up to R meters, the broadcast utilization of v_{1W} becomes: $U = \frac{min(x+\hat{S}B, 2R)}{2R} * 100$. Note that the maximum value of the broadcast utilization is $2R$. By averaging over x, we get the average broadcast utilization as follow:

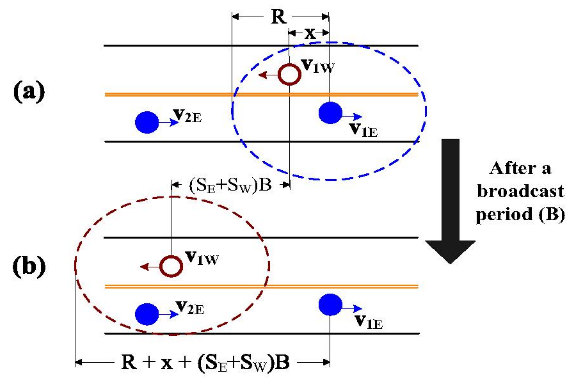

Figure 4. Dissemination of generated data in the opp-dir model.

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

Figure 5 plots the average broadcast utilizations of the generated data in the *same-dir* and the *opp-dir* models. From the figure, the *opp-dir* model performs worse than the *same-dir* model in terms of the broadcast utilization when $(S_E + S_W)B < R/2$. This is due to the third rule of the *opp-dir* model stated earlier in Section 3.2. This rule states that when a vehicle broadcasts its generated data, any vehicle from the opposite direction and within the transmission range could receive and propagate it. Giving the boundary limits of x in the above analysis is $[-R, R]$, many of the broadcasts from vehicles in the opposite direction do not cover any new area especially when the

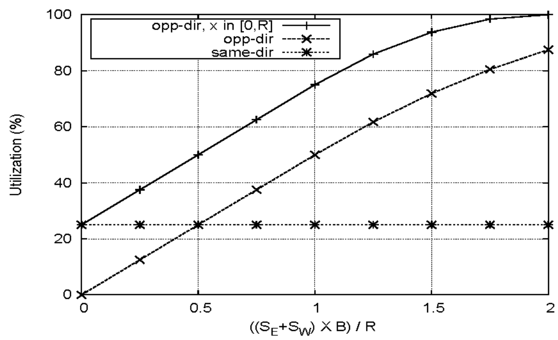

Figure 5. Broadcast utilization for different dissemination models (analytically)

relative speed $\hat{S}$ is small. However, if we increase the lower bound ($-R$) to a higher value, we increase the utilization as we limit the receptions and the broadcasts to only vehicles with expected large new coverage. The average broadcast utilization of the *opp-dir* model when $[0, R]$ is the boundary limits of x is also plotted in Figure 5.

4 Performance Evaluation

In this section we evaluate the performance of the dissemination models defined in the previous section in large scale networks by means of *ns-2* simulator [29] under different scenarios.

In this paper, we make use of the traffic generator tool we developed [27, 28, 15]. This traffic 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 fix the length of the road to 15,000 meters with 4 lanes on each side. We use 802.11b (with a data transmission rate of 11Mbps) as the wireless medium with a transmission range of 250m. During a simulation run, vehicles periodically broadcast their data packets. The broadcast period is selected uniformly from $[1.75, 2.25]$ seconds. Each vehicle recalculates the next broadcast period after it finishes the current broadcast. For all the simulation runs, we use broadcast packets of size 2312 (the maximum payload size of 802.11b standards) and we fix the simulation time to 300 seconds.

4.1 Performance Metrics

In this evaluation, we study the data propagation for vehicles on one side of the road as described in Section 3 and Figure 3. All the metrics in this section are measured with respect to the vehicles moving $East$. We consider the following metrics in evaluating the propagation models:

- *Knowledge Percentage*: The road in front of each vehicle is divided into regions of 500 meters length. For each vehicle, the percentage of the known vehicles in that region to the actual vehicles is defined as the knowledge percentage in that region. The knowledge graph represents the knowledge percentage for each region averaged over all vehicles.

- *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 averaged over all vehicles.

- *Latency Time*: Similar to the previous metrics, the road in front of each vehicle is divided into regions of 500 meters length. The latency time to receive the generated data from the vehicles in each region is calculated. In the latency graphs, the average latency time for each region is averaged over all vehicles.

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

4.1.1 Simulation Results

We experiment with different scenario parameters such as vehicle density, vehicle speed, and broadcast rate. We also study the dissemination models with and without aggregation mechanism. However, due to the space limitation, we limit the results here to the experiments with different vehicle densities in which the aggregation mechanism is used.

To study the effects of vehicle density, we fix the average speed of vehicles to 30m/s, and vary the average gap between consecutive vehicles from 100m (dense traffic) to 500m (regular traffic) to 1000m (sparse traffic).

Figure 6 shows the knowledge graphs for the three dissemination models. As shown, the *opp-dir* and the *bi-dir* models have better knowledge than the *same-dir* model. Although the *bi-dir* model shows better knowledge than the *opp-dir* model, Figure 7 shows that such knowledge has higher errors. For example, for the 500m gap scenario, the average error of the *same-dir* model at distance of 4750m is about 300m. However, the *opp-dir* model reduces this error to 200m only (30% reduction) while the *bi-dir* model

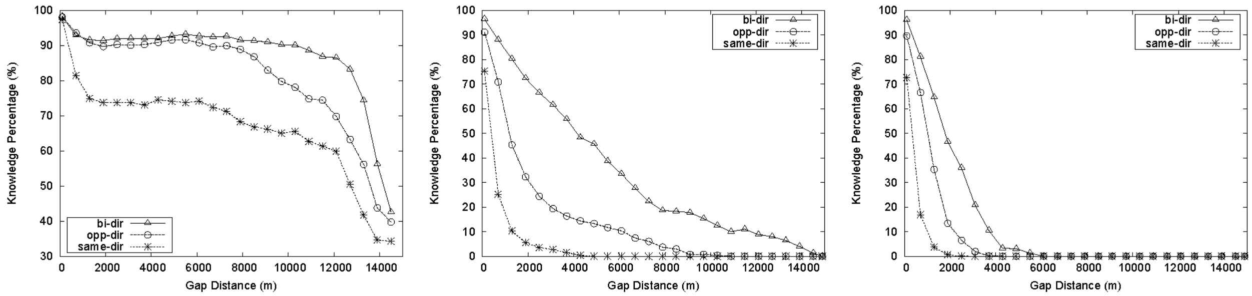

Figure 6. Knowledge graph: (a)Gap=100m, (b)Gap=500m, (c)Gap=1000m

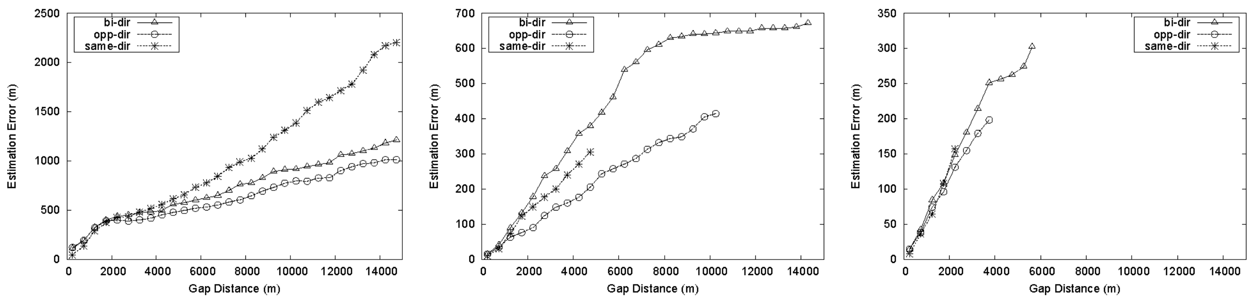

Figure 7. Accuracy graph: (a)Gap=100m, (b)Gap=500m, (c)Gap=1000m

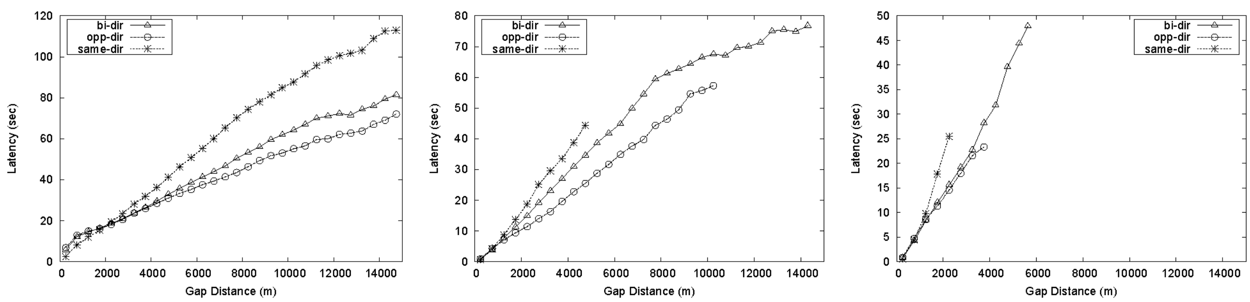

Figure 8. Latency graph: (a)Gap=100m, (b)Gap=500m, (c)Gap=1000m

increases this error to 380m (90% higher than the *opp-dir* error).

Intuitively, the *bi-dir* model should have error rates lower than or equal to the *opp-dir* model since it disseminates information on both directions. Figure 7, however, shows that the *bi-dir* model has higher error rates than the *opp-dir* model. The explanation of this behavior resides in the observation that the data propagation using vehicles in the opposite direction is faster than using vehicles in the same direction. For example, consider Figure 3 where vehicles are driving in both directions and a vehicle wants to disseminate data towards another vehicle three hops away. If the speeds of all vehicles relatively the same, then it would take three broadcast periods for this data to reach the destination when it is disseminated using only vehicles in the same direction. However, when data is disseminated using vehicles in the opposite direction, it propagates faster because vehicles carrying this data travel a certain distance between successive broadcasts. Assume for simplicity that vehicles in the opposite directions, relative to vehicles in the same direction, move a distance equal to the transmission range every broadcast period. Using our example, after the first broadcast, the vehicle in the opposite direction that receives this data could be only two hops away from the destination. By the time this vehicle broadcasts, it is just one hop away from the destination owing to its mobility. Therefore, it could only take two broadcast periods for this data to reach the destination when it is disseminated using vehicles on the opposite direction.

Since data in the *bi-dir* model propagates at different speeds in the two directions, outdated information propagated through vehicles moving in the same direction could overwrite newer data that is propagated through vehicles moving in the opposite direction. This behavior occurs because the aggregation mechanism does not preserve the original timestamps of the data, which make it difficult to correctly compare timestamps and recognize the outdated data. In addition, vehicles in TrafficView use an aging mechanism to purge outdated information. However, purged information with incorrect timestamps may get reinserted again when it arrives later. Refer to [28] for further details on aggregation and aging mechanisms.

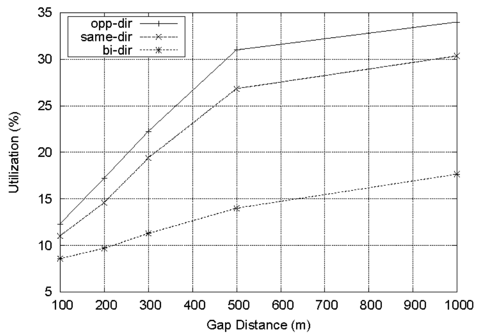

Figure 9. Broadcast utilization for different dissemination models (simulated)

Because of these issues, the *bi-dir* model suffers from low accuracy.

Figure 8 confirms the previous observation that the *bi-dir* model has higher latency than the *opp-dir* model. This figure indicates that information propagated by vehicles traveling in the same direction is received later than information propagated by vehicles traveling in the opposite direction. From this figure, we observe that the difference in performance of the *opp-dir* and the *bi-dir* models is signified with the increase in the gap value (e.g., as the gap changes from 100m to 500m). This is because the difference in propagation speeds of the opposite and the same directions increases as the gap value increases. However, as the gap value becomes very large (e.g., when the gap is 1000m), these differences disappear and the *bi-dir* model behaves similar to the *opp-dir* model because data propagation using vehicles in the opposite direction dominates over the propagation using vehicles in the same direction.

Figure 9 shows the utilization rate for the three models. In this experiments we altered the third rule of the *opp-dir* model stated in Section 3.2 to set the boundary limits of x that is shown in Figure 4 to $[0, R]$. The results bear close correlation to the results obtained from the analytical model shown in Figure 5. Utilization rate is an approximation of the broadcast utilization rate in the analytical model. Utilization rate only takes into consideration useful vehicle information contained in received packets. As expected, the utilization rate increases with the gap value and the *opp-dir* model has the highest utilization rate among all models.

In the above experiments, both road directions (i.e., $East$ and $West$) have the same vehicle density. We experiment with different vehicle densities for different road directions. For experiments with sparse traffic (gap=1000m) in the $East$ direction and a varying density in the $West$ direction between dense traffic (gap=100m) to sparse traffic (gap=1000m), the relative performance of the dissemination models is similar to the previous results with same vehicle density in both directions. However, the performance of the dissemination models becomes different when vehicle density of the $East$ direction varies between dense traffic (gap=100m) and sparse traffic (gap=1000m), while the $West$ direction of the road has sparse traffic (gap=1000m). Figure 10 and Figure 11 show the knowledge, the accuracy, and the latency graphs for 100m and 500m gaps in the $East$ direction and 1000m gap in the $West$ direction. The corresponding graphs for 1000m gap in the $East$ direction and 1000m gap in the $West$ direction are already shown in Figures 6(c), 7(c), and 8(c). These figures show that with high density in the $West$ direction, the *bi-dir* model outperforms the *opp-dir* model. This is because the data propagation in the *opp-dir* model only occurs through sparse density of vehicles (i.e., vehicles in the $West$ direction) and this makes the propagation unreliable. When density in the $East$ direction becomes sparse, the *bi-dir* and the *opp-dir* models have comparable performance. Interestingly, the *bi-dir* model outperforms the *same-dir* model for all densities.

In summary, the performance of the data dissemination model depends on the traffic densities in both directions of the road. When traffic in the opposite direction (e.g., $West$ in our example) is *not* sparse, the *opp-dir* model is more efficient than both the *bi-dir* and the *same-dir* models in terms of average error, latency, and network utilization. Although the *bi-dir* model has better knowledge than the *opp-dir* model in this network configuration, this better knowledge comes with the cost of lower accuracy, higher latency, and lower utilization rate. Therefore, the *opp-dir* model is the most efficient data-dissemination model in terms of efficiency, accuracy, and scalability. However, when traffic in opposite direction is sparse, the *bi-dir* model outperforms both the *opp-dir* and the *same-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. [31] shows that flooding results in severe performance degradation, especially with high node density, as a result of the broadcast storm problem. [23] 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 [12]. [30] proposes a trajectory-based forwarding scheme. [38] 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 [24, 13]. [39]

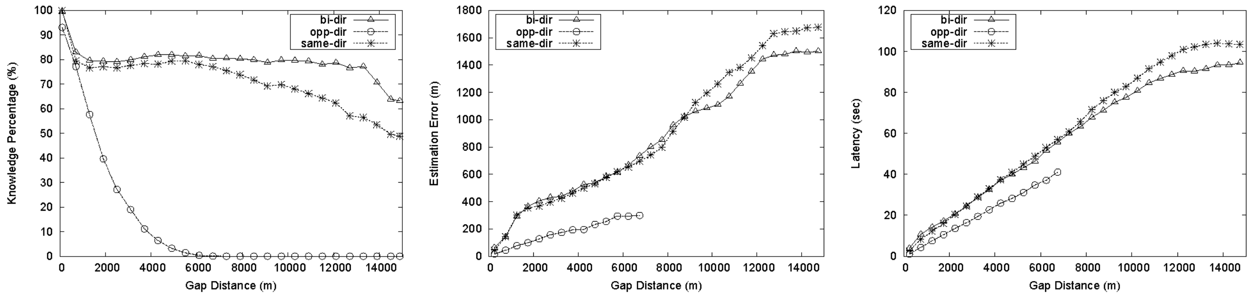

Figure 10. Gap=100m in the East direction: (a)Knowledge graph, (b)Accuracy graph, (c)Latency graph

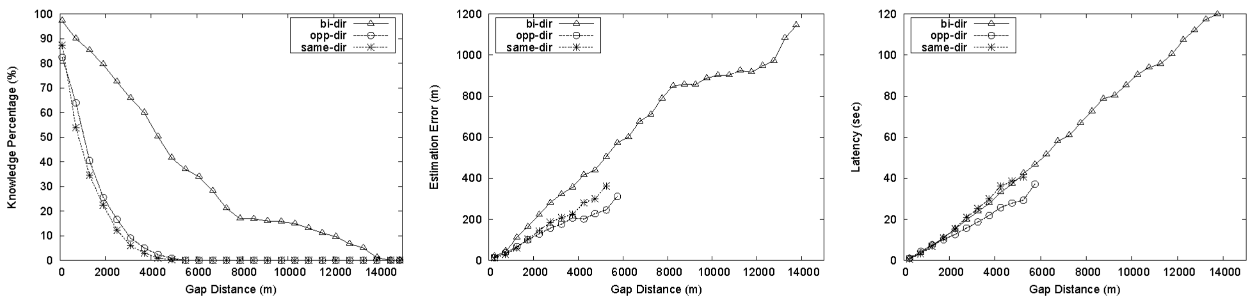

Figure 11. Gap=500m in the East direction: (a)Knowledge graph, (b)Accuracy graph, (c)Latency graph

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.

[20] 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. [36] proposes a broadcast protocol for vehicular ad-hoc networks which performs directed broadcast in the lane of the vehicle. [32] proposes a group communication protocol for a specific scenario, viz. deciding which vehicle should have the right of way at a 4 Way Stop junction. [16] describes an emergency message dissemination protocol for Inter-Vehicle Communication which divides the highway into virtual cells, which move as the vehicles move. [11] proposes a medium access scheme derived from IEEE 802.11 combined with a multi-hopping algorithm for disseminating a message among vehicles in road traffic. The multi-hopping is performed by all vehicles up to a threshold number of hops and does not depend on the lane direction of the vehicle.

To the best of our knowledge, this paper 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 propagating data shows best performance in many scenarios.

In our current system, all vehicles 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 decide whether a car should participate in broadcasting or not. These 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 [33]. In the future, we plan to emulate mobility on Orbit testbed [6] and use it as a platform to evaluate the data dissemination models. We are also investigating several other traffic applications that can benefit from the use of the TrafficView dissemination models.

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References

[1] http://www.quatech.com
[2] http://www.obddiagnostics.com
[3] http://www.its.dot.gov/index.htm
[4] http://www.leearmstrong.com/DSRC/DSRCHomeset.htm
[5] http://discolab.rutgers.edu/
[6] http://www.orbit-lab.org/
[7] "US Census Bureau, Topologically Integrated Geographic Encoding and Referencing system (Tiger Line)," http://www.census.gov/geo/www/tiger.
[8] "US Census Bureau, 2005 Tiger/Line Files by state," http://www.census.gov/geo/www/tiger/tiger2005fe/tgr2005fe.html.
[9] "Wireless on Wheels," *MIT Technology Review*, January 2005.
[10] L. Briesemeister, G. Hommel, "Role-based multicast in highly mobile but sparsely connected ad hoc networks," in *First Annual Workshop on Mobile Ad Hoc Networking and Computing*, pp. 45–50, Aug. 2000.
[11] L. Briesemeister, L. Schäfers and G. Hommel, "Disseminating Messages among Highly Mobile Hosts based on Inter-Vehicle Communication," *IEEE Intelligent Vehicles Symposium*, pp. 522–527, October 2000.
[12] Z.D. Chen, H. Kung, and D. Vlah, "Ad Hoc Relay Wireless Networks over Moving Vehicles on Highways," *2nd ACM international symposium on Mobile ad hoc networking and computing (MobiHoc)*, 2001.
[13] I. Chisalita and N. Shahmehri, "A peer-to-peer approach to vehicular communication for the support of traffic safety applications," *5th IEEE Conference on Intelligent Transportation Systems*, 2002.
[14] CORSIM User Manual, Ver. 1.01, The Federal Highway Administration, US Dept. of Transportation, 1996.
[15] S. Dashtinezhad, T. Nadeem, B. Dorohonceanu, C. Borcea, P. Kang, L. Iftode, "TrafficView: A Driver Assistant Device for Traffic Monitoring based on Car-to-Car Communication," *Proceedings of the IEEE Semiannual Vehicular Technology Conference*, Milan, Italy, May 2004.
[16] M. Durresi, A. Durresi, L. Barolli, "Emergency Broadcast Protocol for Inter-Vehicle Communications," *11th International Conference on Parallel and Distributed Systems (ICPADS'05)*, pp. 402–406, 2005.
[17] General Motors Collaborative Laboratory website available online at `http://gm.web.cmu.edu/`.
[18] Q. Huang, R. Miller, "The Design of Reliable Protocols for Wireless Traffic Signal Systems". Technical Report WUCS-02-45, Washington University, Department of Computer Science and Engineering, St. Louis, MO.
[19] W. Kellerer, "(Auto)Mobile Communication in a Heterogeneous and Converged World," *IEEE Personal Communications*, Vol. 8(6), pp. 41–47, Dec. 2001.
[20] G. Korkmaz, E. Ekici, F. gner and U. gner, "Urban multi-hop broadcast protocol for inter-vehicle communication systems," *1st ACM international workshop on Vehicular ad hoc networks (VANET)*, 2004.
[21] J. Li, J. Jannotti, D. S. J. De Couto, D. R. Karger, R. Morris, "A Scalable Location Service for Geographic Ad Hoc Routing", *ACM Mobicom 2000*, Boston, MA.
[22] Q. Li, D. Rus, "Sending Messages to Mobile Users in Disconnected Ad-hoc Wireless Networks," *ACM Mobicom 2000*, Boston, MA.
[23] W. Lou and J. Wu, "On reducing broadcast redundancy in ad hoc wireless networks," *IEEE Transactions on Mobile Computing*, 2002.
[24] R. Miller and Q. Huang, "An Adaptive Peer-to-Peer Collision Warning System," *IEEE Vehicular Technology Conference (VTC)*, 2002.
[25] R. Morris, J. Jannotti, F. Kaashoek, J. Li, D. Decouto, "CarNet: A Scalable Ad Hoc Wireless Network System," *9th ACM SIGOPS European Workshop*, Kolding, Denmark, Sept. 2000
[26] P. Murphy, E. Welsh, P. Frantz, "Using Bluetooth for Short-Term Ad-Hoc Connections Between Moving Vehicles: A Feasibility Study," *IEEE Vehicular Technology Conference (VTC)*, Birmingham, AL, May 2002.
[27] T. Nadeem, S. Dashtinezhad, C. Liao, L. Iftode, "TrafficView: Traffic Data Dissemination using Car-to-Car Communication," *ACM Mobile Computing and Communications Review (MC2R)*, Vol. 8, No. 3, pp. 6-19, July 2004.
[28] T. Nadeem, S. Dashtinezhad, C. Liao, L. Iftode, "TrafficView: A Scalable Traffic Monitoring System," *Proceedings of the 2004 IEEE International Conference on Mobile Data Management (MDM)*, Berkeley, California, USA, January 19-22, 2004.
[29] Network simulator - ns-2, http://www.isi.edu/nsnam/ns/
[30] D. Niculescu, and B. Nath, "Trajectory Based Forwarding and Its Applications," *9th annual international conference on Mobile computing and networking (MobiCom)*, 2003.
[31] S. Ni, Y. Tseng, Y. Chen, and J. Sheu, "The Broadcast Storm problem in a Mobile Ad Hoc Network," *5th annual international conference on Mobile computing and networking (MobiCom)*, 1999.
[32] E. O'Gorman, "Using group communication to support inter-vehicle coordination," *Master's thesis*, Department of Computer Science, University of Dublin, 2002.
[33] D. Raychaudhuri, I. Seskar, M. Ott, S. Ganu, K. Ramachandran, H. Kremo, R. Siracusa, H. Liu, and M. Singh, "Overview of the ORBIT radio grid testbed for evaluation of next-generation wireless network protocols," *IEEE Wireless Communications and Networking Conference*, 2005.
[34] M. Satyanarayanan, "Pervasive Computing: Vision and Challenges," *IEEE Personal Communications*, Vol. 8(4), pp. 10–17, Aug. 2001.
[35] C. Schwingenschloegl, T. Kosch, "Geocast Enhancements for AODV in Vehicular Networks," *ACM Mobile Computing and Communications Review*, Vol. 6(3), pp. 96–97, Jul. 2002.
[36] M. Sun, W. Feng, T. Lai, K. Yamada, H. Okada, K. Fujimura, "GPS-Based Message Broadcasting for Inter-vehicle Communication," *Proceedings of the Proceedings of the 2000 International Conference on Parallel Processing*, 2000.
[37] E. Welsh, P. Murphy, P. Frantz, "A Mobile Testbed for GPS-Based ITS/IVC and Ad Hoc Routing Experimentation," *International Symposium on Wireless Personal Multimedia Communications (WPMC)*, Honolulu, HI, Oct. 2002.
[38] H. Wu, R. Fujimoto, R. Guensler, M. Hunter, "MDDV: a mobility-centric data dissemination algorithm for vehicular networks," *1st ACM international workshop on Vehicular ad hoc networks*, 2004.
[39] Q. Xu, T. Mak, J. Ko and R. Sengupta, "Vehicle-to-vehicle safety messaging in DSRC," *First ACM workshop on Vehicular ad hoc Networks (VANET)*, 2004.