# PERFORMANCE EVALUATION OF DATA DISSEMINATIONS FOR VEHICULAR AD HOC NETWORKS IN HIGHWAY SCENARIOS

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## ABSTRACT:

A *vehicular ad hoc network* (VANET) is a relatively new term for an old technology – a network that does not rely on pre-existing infrastructure. When integrated into the *intelligent transportation systems* (ITS), it can provide direct *vehicle-to-vehicle* (V2V) and *vehicle-to-infrastructure* (V2I) communications, thereby can greatly improve the safety and efficiency of road traffic. The emerging and promising VANET technology is distinguished from *mobile ad hoc networks* (MANET) and *wireless sensor networks* (WSN) by large-scale deployed autonomous nodes with abundant exterior assisted information, high mobility with an organized but constrained pattern, frequently changed network topology leading to frequent network fragmentation, and varying drivers behavior factors. Without the presence of centralized entities such as *base stations*, mobile hosts also need to operate as routers in order to maintain network connectivity. Therefore, various ad hoc routing protocols have been proposed, but there have previously been few studies on how the specific mobility patterns of vehicles may influence the protocols performance and applicability. In this paper, we compare and evaluate the performance of following routing protocols: AODV, DSDV, and DSR. A variety of highway scenarios, characterized by the mobility, load, and size of the network were simulated. Our results indicate that those routing protocols dedicated for MANET is unsuitable for VANET scenarios in terms of packet delivery ratio, routing load, and end-to-end delay.

## 1. INTRODUCTION

A *vehicular ad hoc network* (VANET) is a specific form of *packet radio networks* (PRNET), as the practical application of *mobile ad hoc networks* (MANET) and *wireless sensor networks* (WSN) on *intelligent transportation systems* (ITS), it can provide direct communications among nearby vehicles, referred to as *vehicle-to-vehicle* (V2V) communications, and between vehicles and nearby fixed equipment, referred to as *vehicle-to-infrastructure* (V2I) communications, thereby can rapidly deploy a self-organizing, non-infrastructure, multi-hop, cost-free, open, and distributed *inter-vehicle communication* (IVC) networks based on pre-established road layouts.

The emerging and promising VANET technology, which has drawn tremendous attention from government, academics, and industry in the past few years, has been envisioned as one of the forefront research hotspots and increasingly available for a large number of cutting-edge applications as diverse as imminent collision warning and avoidance, forward obstacle detection and avoidance, emergency message dissemination, intersection decision support, cooperative driving assistance, traffic congestion advisory, dynamic route update, traveler and tourist information, automated toll collection and parking services, interactive multimedia and internet access.

Most of concerns of interest to MANET are of interest in VANET; however, when compared to the former, the latter has several salient characteristics, such as, large-scale deployed autonomous nodes or terminals with abundant exterior assisted information (e.g., in-vehicle *global positioning system* (GPS), *geographic information system* (GIS), lidar, and video camera), high mobility with an organized but constrained pattern (e.g., by being restricted to follow a paved highway), frequently changed network topology leading to frequent network fragmentation, and varying drivers behavior (e.g., direction/lane changing or overtaking). Furthermore, the *on-board unit* (OBU) and *roadside unit* (RSU), by which may provide mobile ad hoc inter-connectivity, generally do not have distinct energy constraints due to their access to external power supply systems. Therefore, the conventional research dedicated for MANET cannot be directly applied to VANET since those afore-mentioned characteristics are not well considered.

To facilitate the safe, secure, efficient, clean, and comfortable mobility of people and goods, advanced communication and information exchange between the key elements of the mobility sector – *the user*, *the infrastructure*, and *the vehicle* – are required. Nodes in VANET can communicate with each other at any time and without any restriction, except for connectivity limitations and subject to security provisions. Different mobility patterns and radio propagation conditions can result in a space-time varying network topology. A VANET, other than legacy *client-server* (C/S) communications, is a *peer-to-peer* (P2P) network which allows direct communications between any two nodes. If there is no direct link between the source and the destination, multi-hop routing is used. Various ad hoc network routing protocols have been proposed in the literature, and can be coarsely classified into *topology-based* and *position-based* approaches (Mauve et al., 2001).

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Topology-based routing protocols, which can be further divided into *proactive*, *reactive*, and *hybrid* approaches, use the information about the links that exist in the network to perform packet forwarding. Proactive routing protocols employ classical routing strategies such as *distance-vector* routing (e.g., DSDV (Perkins and Bhagwat, 1994)) or *link-state* routing (e.g., OLSR (Clausen et al., 2003) and TBRPF (Ogier et al., 2000)). They maintain routing information about the available paths in the network even if these paths are not currently used. The main drawback of these approaches is that the maintenance of unused paths may occupy a significant part of the available bandwidth if the topology of the network changes frequently (Das et al., 2000b). Reactive routing protocols, such as AODV (Perkins and Royer, 1999), DSR (Johnson and Maltz, 1996), and TORA (Park and Corson, 1997), maintain only the routes that are currently in use, thereby reducing the burden on the network when only a small subset of all available routes is in use at any time. Hybrid routing protocols, such as ZRP (Haas and Pearlman, 2001), combine local proactive routing and global reactive routing strategy in order to achieve a higher level of efficiency and scalability.

Position-based routing protocols require additional information about geographical position of participating nodes. Commonly, each node determines its own position through the use of GPS, and then made available to the adjacent neighbors in the form of periodically transmitted beacons. A sort of *location service* is used by the sender of a packet to determine the position of the destination and to include it in the packet's destination address. The routing decision at each node is based on the destination's position contained in the packet head and the position of the forwarding node's one-hop neighbors. Position-based routing algorithms thus does not require establishment or maintenance of routes, which means that nodes have neither to store routing tables nor to transmit messages to keep routing tables up to date. Examples for position-based routing protocols are DREAM (Basagni et al., 1998), face-2 (Bose et al., 2001), GPSR (Karp and Kung, 2000), and terminode routing (Blazevic et al., 2000).

The objective of this paper is to evaluate routing performance of those two classes. We will mainly study and compare the following algorithms knows as AODV, DSDV, and DSR, using extensive simulation experiments. The remainder of this paper is organized as follows: Section 2 outlines the related work, Section 3 presents the simulation models, including highway mobility and network evaluation models, Section 4 discusses the simulation results, and Section 5 concludes the paper.

## 2. RELATED WORK

Several recent efforts are the most related to our work, as they also use simulation-based methodology (e.g., NS-2 or QualNet). (Broch et al., 1998) is the first to provide a realistic, quantitative analysis comparing the relative performance of the four mobile ad hoc network routing protocols (AODV (Perkins and Royer, 1999), DSDV (Perkins and Bhagwat, 1994), DSR (Johnson and Maltz, 1996), and TORA (Park and Corson, 1997)). They simulated 50 wireless nodes, moving according to the *random waypoint* (RWP) model over a rectangular (1500m×300m) flat space for 900 seconds. The mobility patterns were generated with 7 different pause time (0, 30, 60, 120, 300, 600, and 900 seconds) and with 2 different maximum node speed (1 and 20 mps). The type of communication patterns was chosen to be constant bit rate (CBR), and the parameters experimented with 3 different communication pairs (10, 20, 30 traffic sources), each sending 1, 4, and 8 packets per second (packet sizes of 64 and 1024 bytes). Packet delivery fraction, number of routing packets transmitted, and distribution of path lengths were chosen as the performance metrics. Simulation results demonstrated that DSR and AODV performed significantly better than DSDV, and TORA acted the worst in terms of routing packet overhead. (Boukerche, 2002; Das et al., 2000a; Johansson et al., 1999; Perkins et al., 2001) did similar performance analysis of topology-based routing algorithms.

(Hsu et al., 2003) presented a comprehensive study on the performance of topology-based routing protocols under realistic network scenarios. The routing protocols used include AODV (Perkins and Royer, 1999), DSR (Johnson and Maltz, 1996), OLSR (Clausen et al., 2003), OSPF version 2 (which represents a traditional wired link-state routing protocol), and ZRP (Haas and Pearlman, 2001). The simulated mobility scenario, based on a 4-hour field test, involved 1 static node (e.g., base station) and 19 mobile nodes, which follow a dual counter rotating ring mobility pattern comprising of an inner loop and an outer loop. The 14 outer loop nodes rotate clockwise whereas the 5 inner loop nodes rotate counter-clockwise. Mobility of the nodes was simulated using GPS logs and traffic patterns generated fell into five categories, ranging from high rate traffic (120 or 200 kbps of 1 KB packets) to low rate traffic (800 bps of 100 B packets). The network throughput, packet delivery ratio, and end-to-end delay were chosen as performance metrics. Simulation results show that AODV performed to be vastly superior to the other compared routing protocols in this type of scenario.

(Boukerche, 2004) presented an extensive simulation studies to compare the performance of five routing protocols: AODV (Perkins and Royer, 1999), PAODV (Pre-emptive AODV) (Boukerche and Zhang, 2004), CBRP, DSR (Johnson and Maltz, 1996), and DSDV (Perkins and Bhagwat, 1994), using a variety of workload and scenarios, such as mobility, load, and size of the ad hoc networks. Simulation results indicated that despite the improvement in reducing route request packets, CBRP has a higher overhead than DSR because of its periodic hello messages while AODV's end-to-end packet delay is the shortest when compared to DSR and CBRP. PAODV has shown little improvements over AODV.

(Choudhury and Vaidya, 2005) evaluated the impact of directional antennas on the performance of ad hoc routing (e.g., DSR, which is originally designed for omnidirectional antennas). Performance evaluation suggested that using directional antennas may not be suitable when the network is dense or linear; however, the improvement in performance is encouraging for networks with sparse and random topologies.

More recent work on performance evaluation and comparisons of routing protocols in mobile ad hoc networks include (Lahde, 2007; Peiyan and Layuan, 2006; Trung et al., 2007). While communication between vehicles is frequently mentioned as a target for ad hoc routing protocols, there have previously been few studies on how the specific mobility patterns of vehicles may influence the protocols performance and applicability. Typically, the behavior of routing protocols for mobile ad hoc networks is analyzed based on the assumption that nodes in the networks follow the random waypoint model (Bettstetter et al., 2004; Bettstetter et al., 2003). Since this movement pattern of nodes has no similarity to the behavior of vehicles, the random waypoint model seems to be inappropriate to investigate the characteristics of vehicular ad hoc networks or to determine which data dissemination protocols are suitable for vehicular ad hoc networks.

To the best of our knowledge, (Füßler et al., 2002) analyzed the quantitative behavior of ad hoc routing algorithms for data dissemination between vehicles, and evaluated the performance of a reactive ad hoc routing protocol (DSR (Johnson and Maltz, 1996)) and of a position-based approach (GPSR/RLS (Karp and Kung, 2000)). Simulation results suggested that position-based ad hoc routing protocol has significant advantages over reactive non-position-based approach. In contrast to highway scenarios, (Lochert et al., 2003) first evaluated ad hoc routing protocols over a realistic vehicle mobility pattern for a city scenario, and presented a simulation study that compares a position-based routing (GSR) approach with classical ad hoc routing methods (AODV(Perkins and Royer, 1999) and DSR(Johnson and Maltz, 1996)). Simulation results also demonstrated that position-based routing outperforms topology-based approaches with respect to delivery rate and latency.

(Jaap et al., 2005) also evaluated the performance of routing protocols (AODV(Perkins and Royer, 1999), DSR(Johnson and Maltz, 1996), FSR, and TORA(Park and Corson, 1997)) in city traffic scenarios, and found out that TORA is completely unsuitable for vehicular environment, whereas AODV and FSR showed promising results, DSR suffered from very high end-to-end delay.

(Naumov et al., 2006) studied the behavior of routing protocols (AODV(Perkins and Royer, 1999) and GPSR(Karp and Kung, 2000)) in an inner city environment and on a highway segment by using realistic mobility traces obtained from a microscopic vehicular traffic simulation on real road maps of Switzerland. Both exhibit serious performance problems in the investigated VANET scenarios.

## 3. SIMULATION MODELS

### 3.1 Highway mobility model

Vehicular mobility models can be classified as *macroscopic* and *microscopic*(Haerri et al., 2006).When following a macroscopic approach, motion constraints (e.g., roads, crossings and traffic lights) are considered and generation of vehicular traffic (e.g., traffic density, traffic flows, and vehicle distributions) are also defined. In contrast, with a microscopic approach the movement of each individual vehicle and the vehicle behavior with respect to others are determined. It is obvious that the combination of micro-macro approach is more suitable for vehicular mobility model. We developed a mobility scenario for highway traffic in China, which is modeled as 2×2 scenario, viz. bidirectional, two lanes each scenario. Vehicles can move along roadways with high speed towards the two opposite directions, which are separated by the median zone. The two lanes in each direction can be further divided into normal-speed (right-hand side) and overtaking (left-hand side). We depict our highway scenario in Figure 1, without loss of generality. The width of each lane and median is taken as 3.75m and 2.00m, respectively.

In our highway scenarios, we assume that all vehicles follow the directional mobility model, in which each vehicle randomly selects a waypoint ahead in the same direction and then moves from its current position to the selected waypoint. The running speed is determined by the *intelligent driver model* (IDM) (Treiber et al., 2000), which belongs to the class of car-following model. As shown in figure 1, the instantaneous acceleration of vehicle *i* is denoted as follows:

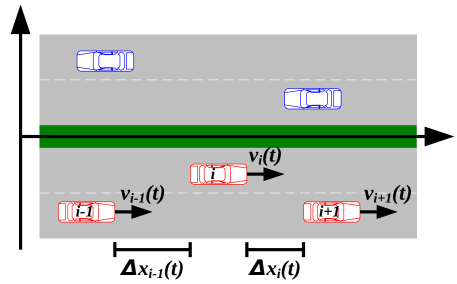


Figure 1. A segment of highway scenarios

$$\dot{v}_i^{\,IDM}(v_i, s_i, \Delta v_i) = a_{\max}^{(i)}\left[1-\left(\frac{v_i}{v_{des}^{(i)}}\right)^{\delta} - \left(\frac{s^*(v_i,\Delta v_i)}{s_i}\right)^2\right] \quad (1)$$

where, $v$ is the current instantaneous speed

$v_{des}$ is the desired velocity

$\Delta v$ is the velocity difference (approaching velocity) to the preceding vehicle

$a_{max}$ is the maximum acceleration

$\delta$ is the acceleration exponent

$s^*$ and $s$ are the desired distance and actual distance gap between adjacent vehicles on the same lane, respectively; subscript $i$ or superscript $(i)$ represents corresponding parameters of the vehicle $i$.

The first two items interpret the vehicle's running acceleration on freeways, and the third describes the desired deceleration in case of vehicle *i* approaches to the vehicle in front. The desired distance gap of vehicle *i* is denoted as follows:

$$s^{*\,IDM}(v,\Delta v) = s_0^{(i)} + s_1^{(i)}\sqrt{\frac{v}{v_{des}^{(i)}}} + T^{(i)}v + \frac{v\cdot\Delta v}{2\sqrt{a^{(i)}b^{(i)}}} \quad (2)$$

where, both $s_0$ and $s_1$ are the jam distance

$T$ is the safe time headway

$a$ is the maximum acceleration

$b$ is the desired deceleration

### 3.2 Network evaluation model

The network evaluation model assumes that all the vehicles are equipped with wireless transceivers, by which can dynamically construct ad hoc networks on the fly. The nodes in the network act as either a host (sender/receiver) or a router to perform data disseminations. We model the network as a communication graph G={V(G), E(G)}, where the vertex set V(G)={$v_1$, $v_2$, …, $v_n$} represents all the participating vehicles in the network, and the edge set E(G)={($v_i$, $v_j$) | distance($v_i$, $v_j$) ≤ R and i ≠ j} represents all the communication links between corresponding nodes if and only if both are within the transmission range R of each other; thereinto, distance($v_i$, $v_j$) is defined as the *Euclidean* *distance* of node $v_i$ and $v_j$. At each simulated timestamp, the network model tries to construct the graph G by searching for a path that connects each communication pair. The existence of such paths indicate the possibility of routing data packets along the path.

Supposing that the width of a road is far less than the range of *radio frequency* (RF), the IVC networks constructed in highway scenarios can be regarded as 1-dimensional (Franz et al., 2005), and the destination is located either in front of the sender or somewhere behind. To make it easier to understand, we propose the following assumptions:

- Not considering the *multipath effects*, which is the term given to the phenomenon where a radio signal arrives at the receiving antenna after being reflected off a surface, so if two arbitrary nodes located within the transmission range of each other, we deem that only one wireless communication link exists.
- Symmetrical link path, which mainly appears that the bandwidth and the radio transmission range of all the nodes in the network are symmetrical. If node A can communicate with node B, then node B can also communicate with node A.
- Considering *border effects*, which we can disable the nodes iff they are located out of the observation scenario at that moment, thus they cannot participate in the network or forward the message.

## 4. SIMULATION RESULTS

To further study how the features of each protocol affect their performance of data disseminations, we did an extensive performance comparison using the implementations of these protocols in ns-2 with CMU wireless extensions under Linux. The common parameters we used in the simulations are listed in Table 1.

We obtained the original mobility scenario from the FleetNet (Füßler et al., 2006) project, and the dataset comprises each vehicle's *position* (X), *lane*, *speed*, and *acceleration* values at each *timestamp*. We preprocessed the data in accordance with the highway scenarios in China. Due to the lane information only in the dataset, the action of lane-changing is usually done between the two adjacent simulation timesteps. We mapped each vehicle's lane into its *position* (Y) based on the system of coordinates demonstrated in Figure 1, that is:

$$PositionY = (Lane \mp 0.5) \times LaneWidth \pm 0.5 \times MedianWidth, Lane = \pm 1, \pm 2. \quad (3)$$

| **Parameter** | **Simulated Value** |
|---|---|
| Channel type | Wireless channel |
| Antenna model | Omnidirectional antenna |
| Radio propagation model | Two ray ground |
| Network interface type | Lucent WaveLAN (915MHz) |
| Nominal radio range | 250m |
| MAC type | IEEE 802.11 DCF |
| Interface queue type | Priority queue (50 packets max.) |
| Number of nodes | 108/240/374/500 |
| Simulation time | 60s |
| X dimension | 12km |

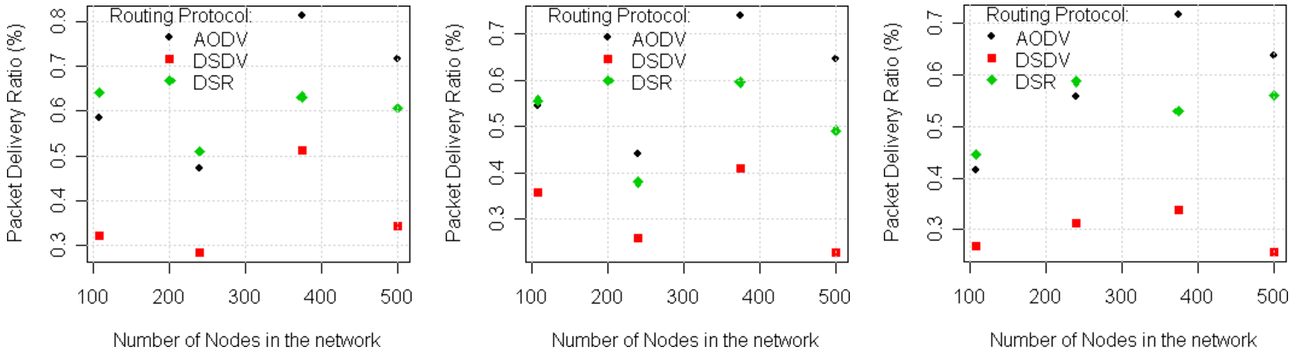
Table 1. Simulation parameters

The traffic sources are *constant bit rate* (CBR), generated with the help of *cbrgen.tcl* script, and only 512-byte data packets are used. The randomly chosen source-destination pairs are spread in the network. The percentage of the communication pairs is varied from 10% to 30% for evaluating the load of the network.

Three important performance metrics are evaluated:

- Packet delivery fraction – the ratio of the data packets received to the data packets sent;
- Normalized routing load – the ratio of the routing packets delivered to the data packets received;
- Average end-to-end delay – this includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, and propagation time.

Figure 2 shows the packet delivery fraction of different ad hoc routing protocols vs. number of nodes in the network; thereinto, Figure 2(a) is for 10 percent of the communication pairs, 2(b) is for 20 percent of the communication pairs, and 2(c) is for 30 percent of the communication pairs. We understand that AODV and DSR have similar performance, the former outperforms the latter for larger network size measured in the number of nodes, whereas the latter outperforms the former for smaller network size. The DSDV is totally unsuitable for our mobility scenarios, especially in the case of higher percent of communication pairs in networks, where no more than 35% of data packets delivered successfully.

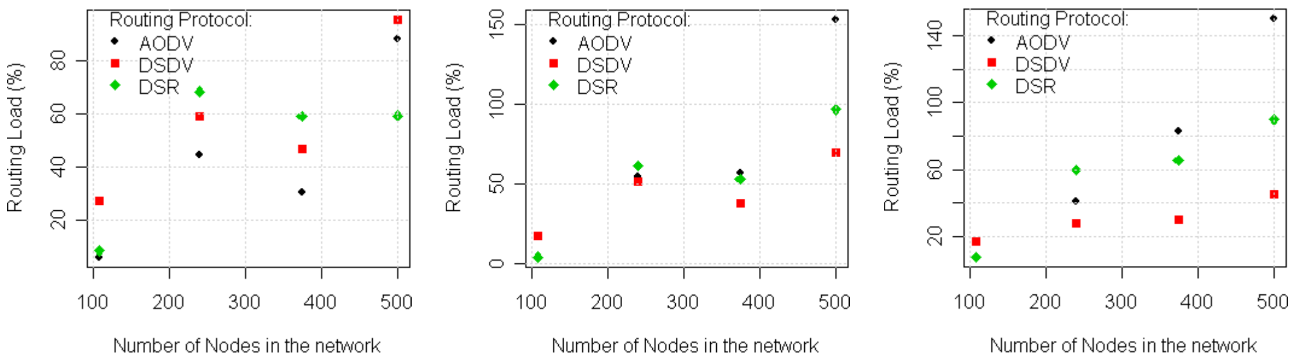


2(a) 10% communication pairs

2(b) 20% communication pairs

2(c) 30% communication pairs

Figure 2. Packet delivery ratio vs. number of nodes



3(a) 10% communication pairs 3(b) 20% communication pairs 3(c) 30% communication pairs

Figure 3. Routing load vs. number of nodes

Figure 3 illustrates the routing load of different ad hoc routing protocols vs. number of nodes in the network; thereinto, Figure 3(a) is for 10 percent of the communication pairs, 3(b) is for 20 percent of the communication pairs, and 3(c) is for 30 percent of the communication pairs. We understand that the AODV in general has higher routing request, especially for larger network size and higher percentage of communication pairs. The DSDV and DSR have a comparatively stable routing load overhead in different mobility scenarios.

## 5. CONCLUSIONS

Recent advances in automobile electronics, wireless communication, and pervasive computing have enabled the development of the *vehicular ad hoc network* (VANET), which is a brand new term for an old technology – a network that does not rely on pre-established infrastructure or centralized administration. When integrated into the *intelligent transportation system* (ITS), it can provide direct *vehicle-to-vehicle* (V2V) and *vehicle-to-infrastructure* (V2I) communications, thereby can greatly improve the safety and efficiency of road traffic. However, many problems remain to be solved before this emerging & promising technology becomes a commonplace.

In this paper, we focus on the routing performance in vehicular ad hoc networks. We present an extensive simulation studies to compare the following routing protocols: AODV, DSDV, and DSR, using a variety of highway scenarios, characterized by the mobility, load, and size of the networks. Our simulation results indicate that those routing protocols dedicated for MANET is totally unsuitable for VANET scenarios in terms of packet delivery ratio, routing load, and end-to-end delay.

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