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Performance Evaluation of AODV and AOMDV with Probabilistic Relay in VANET Environments

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***Abstract*—Vehicular ad hoc networks (VANETs) are the specific class of Mobile ad hoc networks (MANETs). Since vehicles tend to move in a high speed, the network topology is rapidly changed. Thus vehicle's connectivity problem is one of the interesting issues in VANETs. Ad hoc on-demand multipath distance vector (AOMDV) is the extended version of ad hoc on-demand distance vector (AODV). AOMDV is designed to overcome a connectivity problem due to highly dynamic network topology. It provides multipath for data packets delivery from the source to the destination. Although AOMDV outperforms AODV in packet delivery ratio, AOMDV's multipath establishment and maintenance generate more control packets than AODV's unipath. However increasing the vehicle speed will degrade their performance. Thus in this paper, we added probabilistic relay, which enables adjacent vehicles to probabilistically relay unsuccessful data packet transmission, into IEEE 802.11 as a MAC standard model and combined AODV with probabilistic relay (AODV-PR) and AOMDV with probabilistic relay (AOMDV-PR). Based on our simulation result, the addition of probabilistic relay clearly helps those protocols to improve their performances especially in packet delivery ratio even under a high speed. Moreover, probabilistic relay adds beacons, but no additional routing overhead. Probabilistic relay, clearly solved connectivity problem in highly dynamic topology of VANETs. We evaluate those protocol performances based on packet delivery ratio, routing overhead, and average delivery delay under variation of vehicle speed.**

***Index Terms*—IEEE 802.11, Probabilistic Relay, Routing Protocols, VANETs**

I. Introduction

Vehicular ad-hoc networks (VANETs) are an extended class of Mobile ad-hoc networks (MANETs). As a class of wireless ad-hoc networks, their nodes are self-organized and distributed. Apart from their similarities, highly dynamic topology and vehicle mobility are the main differences that make research in VANETs become more challenging than in MANETs. Due to highly dynamic topology, connectivity problem becomes one of the interesting issues in VANETs. Many routing protocols have been proposed to adapt into VANET unique characteristics. However, we are interested in multipath mechanism of ad hoc on-demand multipath distance vector (AOMDV) routing [1] to solve connectivity problem in VANETs. AOMDV is the extended work of ad hoc on-demand distance vector (AODV) routing [2]. The main difference is that AODV provides a unipath while AOMDV has multipath to reach the destination. It has been proved through performance comparison between AODV and AOMDV by Biradar et al. [3] that AOMDV has outperform AODV in packet delivery ratio. Other studies [4], [5], [6], [7], [8] try to solve connectivity problem by exploiting sender-diversity by using multiple connectivities together in several base stations to successfully reduce connectivity disruption. However, these research mostly consider connectivity between a moving vehicle and a static base station. Balasubramanian et al. [4] explored sender diversity to improve the connectivity among static basestation with moving vehicle. Similar to cellular technology, it occupies several static basestation to communicate with moving vehicle. A basestation sends and receives packets to and from a moving vehicle. Auxiliary basestations probabilistically relay undelivered packets to the anchor or the vehicle. The relaying probability is calculated independently by other auxiliary basestations, based on the reception probability recorded through the exchange of beacon messages. Chen et al. [9] proposed R-S-AOMDV by combined hop-count, link-quality and vehicle motion information as its routing metrics to adapt into VANET characteristics. However in this paper, we do not concern to any modification of routing protocols to be adaptable into VANET environments. We focus on applying probabilistic relay into basic form of routing protocols and evaluate their performances under VANET scenario.

Thus, in this paper we extend our study [10] by adopting the work of Balasubramanian et al. [4] for vehicle-to-vehicle communication. We add probabilistic relay into AODV and AOMDV then compare their performances. We called those modified protocols AODV-PR and AOMDV-PR. It shows that the addition of probabilistic relay clearly improved their performances. Moreover, probabilistic relay does not change the behavior of routing protocols.

The rest of this paper is organized as follows: In Section II, we briefly describe ad hoc on-demand distance vector and ad hoc on-demand multipath distance vector. In Section III, we explain the basic of probabilistic relay and how it works. Section IV presents performance evaluation settings and parameters for evaluating the protocols under realistic VANET scenarios and discusses the simulation results. Finally, in Section V we give our conclusions and future work.

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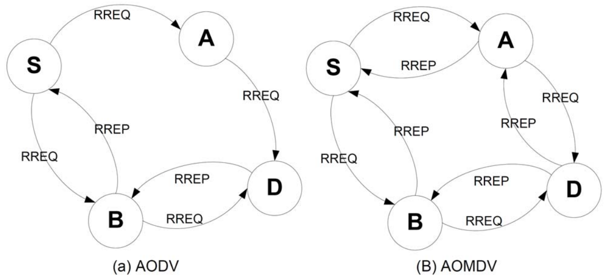

Fig. 1. Route Discovery

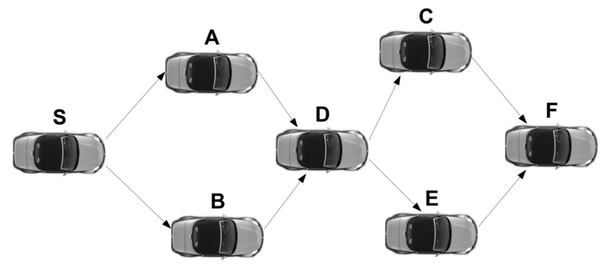

Fig. 2. Ad hoc On-demand Multipath Distance Vector

II. Routing Protocols

In this section, we give a brief introduction about routing protocols that we add probabilistic relay into. We select AODV and AOMDV, reactive protocols, as our routing protocols because of their lower routing overhead than proactive and position-based protocols. In highly dynamic topology environment of VANETs, proactive and position-based protocols need to update their routing information and position information more frequent. While reactive protocols only maintain their routing information if there is a data packet need to be sent. Thus, reactive protocols are the best choice to adapt into VANET environments.

A. Ad hoc On-demand Distance Vector

Ad hoc on-demand distance vector (AODV) routing protocol [2] is one kind of reactive protocols. AODV create a route only when it needed. This on-demand behavior clearly produce lower routing overhead than proactive protocols. When a source has a data packet to send to a destination, it starts route discovery process by disseminating a route request (RREQ) message through the network. If a node receives RREQ which has not been seen before and does not know any route to the destination, it marks a reverse path to the sender and rebroadcasts it through the network. If the node knows about a route to the destination or the node is the destination itself, it sends a route reply (RREP) message back to the source using established reverse path. After the source receives RREP, it finally has a route to send data packets to the destination.

Fig. 1(a) shows AODV route establishment. After the route from the source to the destination is created, the route need to be maintained properly. Due to highly dynamic topology, link breakage occurs frequently. A node detects disconnected link from the periodic exchange of hello message. If disconnected link detected, node broadcasts route error (RERR) message that contains a list of unreachable nodes and their information. If the disconnected link is an active route, node tries to repair it locally by sending RREQ to find a new route to the destination. If the new route is discovered, it updates the entry in its routing table.

B. Ad hoc On-demand Multipath Distance Vector

Since VANET environments are highly dynamic, having multipath instead of unipath to the destination is preferable. Ad hoc on-demand multipath distance vector (AOMDV) routing protocol [1] is an extended version of AODV. AOMDV provide multipath to reach the destination, while AODV only have a unipath to the destination. Despite of their difference, both protocols share the same behavior in several things such as reactive protocol, route discovery mechanism, route maintenance. However, AOMDV in particular has extra RREP and RERR for multipath discovery and maintenance along with a few extra fields in routing control packets. Thus it cost more routing overhead than AODV. Fig. 1(b) shows AOMDV route establishment.

Another modification in AOMDV is the way they keep loop-free and disjoint path. AODV route limit a node to have at most one path for each destination. However, to have multipath for one destination which are satisfied loop-free and disjoint condition needs more attention. Thus AOMDV updates several rules which concern about route acceptance and route advertisement to keep loop-free and disjoint path. In order to satisfy both condition, node need to follow these rules; First, for the same destination sequent numbers, nodes never advertise a route shorter than one already advertised. Second, nodes never accept a route longer than one already advertised. Those two rules could guarantee that AOMDV keep loop-free and disjoint path. The illustration of AOMDV for vehicle-to-vehicle communication shown in Fig. 2. Assume that vehicle S wants to send a data packet to vehicle F. After the exchange of RREQ and RREP followed loop-free and disjoint rules, vehicle S has two possible paths S-A-D-C-F and S-B-D-E-F to reach vehicle F.

III. Probabilistic Relay

The idea of probabilistic relay is initially proposed by Balasubramanian et al. [4] to enable adjacent basestations to relay undelivered packet instead of waiting for retransmission. They deploy probabilistic relay into static basestations to communicate with moving vehicles. In this paper, we extend their works [4] by deploying probabilistic relay for vehicle-to-vehicle communication. Balasubramanian et al. [4] also examined the nature of lost packets which state that retransmission of undelivered packet by the same source is not a better option than another basestation that can help to retransmit packet. As it shown in Fig. 3, the transmission from vehicle S to vehicle D is dropped. In a normal case of WLAN standard IEEE 802.11, vehicle S executes retransmission until

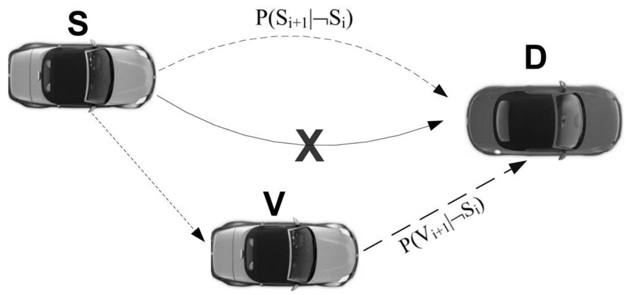

Fig. 3. Probabilistic Relay for Vehicle Communication

maximum number of retry. On the other hand, probabilistic relay allow vehicle V, which overhears the transmitted packet by vehicle S and hears that no acknowledgment was sent by node D, to relay undelivered packet to vehicle D. $P(S_{i+1}|\neg S_i)$) is the conditional reception probability of the (i+1)-th packet from vehicle S, given that the transmitted i-th packet from vehicle S to vehicle D is lost. While, $P(V_{i+1}|\neg S_i)$) is the conditional reception probability of the (i+1)-th packet from vehicle V to vehicle D, after the transmission of i-th packet from vehicle S is failed. Balasubramanian et al. [4] has been proved that, $P(V_{i+1}|\neg S_i)$) is larger than $P(S_{i+1}|\neg S_i)$). Thus, having adjacent vehicle to relay unsuccessful packet transmission is a better way than waiting for retransmission.

It is possible to have more than one adjacent vehicles relay undelivered packet. Thus, to avoid collisions, each adjacent vehicle probabilistically retransmit undelivered packet based on its own relaying probability calculation. We assume $V_i, \ldots, V_j$ ($j > 1$) are the adjacent vehicles, and relaying probability, r_i, of vehicle V_i can be calculated locally by vehicle V_i based on periodic beacons, which include information about reception probability of other vehicles from the surrounding neighbors. Reception probability, P_{ij}, is calculated by using the number of node i's beacons received by node j for a particular time interval divided by the number that must have been sent. These incoming reception probabilities are maintained as exponential averages ($\alpha = 0.5$) over the per-second beacon reception ratio. We calculate r_i using this formula, $r_i = r \cdot P_{V_iD}$, where r can be calculated based on Eq.(1).

$$r = \frac{1}{\sum_{j=1}^{k} P_{SV_j}(1 - P_{SD}P_{DV_j})P_{V_jD}} \tag{1}$$

P_{ij} is the probability that node j receives the packet from node i where $i, j \in \{S, D, V_1, \ldots, V_k\}$. While $(1 - P_{SD}P_{DV_i})$ is the probability that V_i does not hear an acknowledgment from node D.

The addition of probabilistic relay does not change AODV and AOMDV behavior. It only changes on the way the link layer deals with undelivered unicast transmission. It does not respond to broadcasted transmission. For example in AODV and AOMDV, only unicasted data packet, RREP and REER are probabilistically relayed, while broadcasted HELLO, RREQ and REER are never relayed.

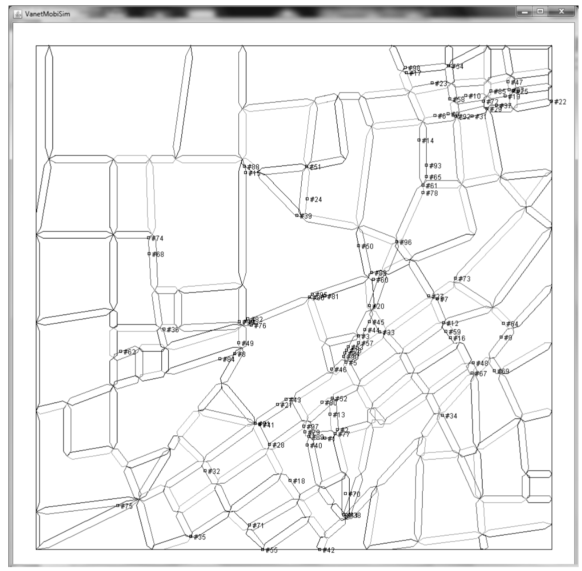

Fig. 4. City Map

IV. Performance Evaluation

In this paper, we compare AODV and AOMDV with and without probabilistic relay through network simulator ns-2.34. We show that the addition of probabilistic relay into AODV as a retransmission control policy can produce very competitive result compare to multipath mechanism of AOMDV performance under VANET environments.

For our realistic mobility scenarios, we use a real city map of Kumamoto, Japan, shown in Fig. 4 generated by VanetMobiSim [11]. We use IEEE 802.11p as the standard model for Wireless Access in Vehicular Environments (WAVE) [6], [12] for our MAC model in the simulations and limit the transmission range of the vehicle to 250 meters. We also adopt the IEEE 802.11p simulation parameters used by Chen et al. [13]. They set up the parameters for 802.11Ext and WirelessPhyExt in a tcl script to implement the IEEE 802.11p vehicular communication standard. Our simulation time is 500 seconds, but data packet transmission started at 300 seconds.

TABLE I
Simulation Parameters

Network Simulator	ns2.34
Simulation Time	500 seconds
Simulation Area	1000 × 1000 meters^2
Number of Vehicles	100 vehicles
Total Data Packets Sent	200 packets
Data Type	Constant Bit Rate (CBR)
CBR Interval	1 second
Data Packet Size	512 bytes
Number of Connections	1 UDP connection
Propagation Model	Nakagami
MAC Protocol	IEEE 802.11p
Routing Protocol	AODV, AOMDV
Radio Range	250 meters
Maximum Vehicle Speed	10, 20, 30 m/s (36, 72, 108 km/h)

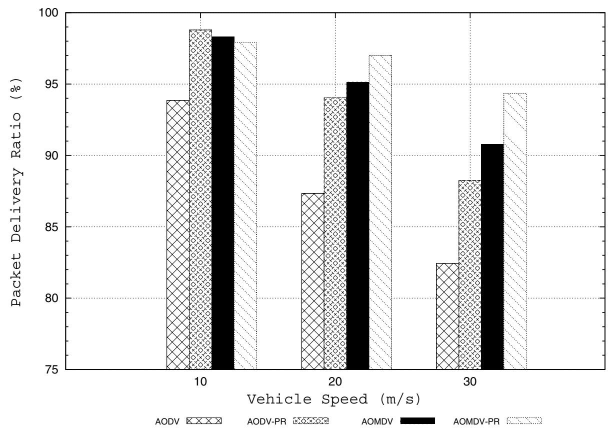

Fig. 5. Packet Delivery Ratio of Various Vehicle Mobilities

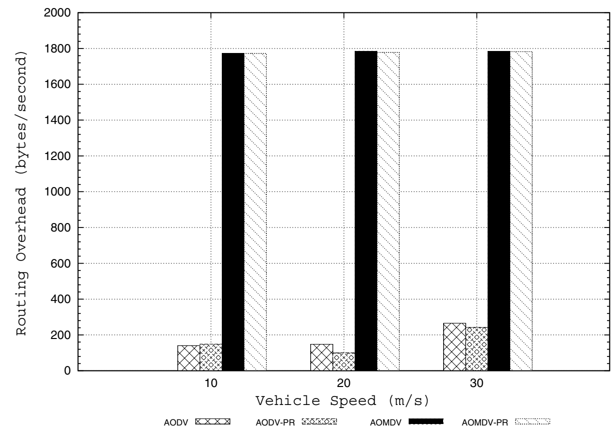

Fig. 6. Routing Overhead of Various Vehicle Mobilities

We simulated each protocol at different vehicle speeds. Five pairs of sources and destinations are randomly picked and calculate their average simulation result. The complete setup of our simulation parameters are shown in Table I. We measure protocol performance in our evaluation based on these following metrics:

- Packet delivery ratio (PDR): the ratio between the number of data packets delivered to the receiver and the number of data packets sent by the source.
- Routing overhead: the total size of routing packets required to construct and maintain the routes.
- Average delay: the average difference between the time a data packet is originated by the sender and the time this packet reaches its destination.

For our first observation, Fig. 5 shows the effect of vehicle mobilities on the PDR. AODV-PR and AOMDV-PR are the routing protocols combined with probabilistic relay. Both AODV-PR and AOMDV-PR outperform their original form. It has been confirmed that the addition of probabilistic relay clearly help routing protocols to improve their PDR. Because of the capability of relaying the unsuccessful data packet transmissions than does the common retransmission of the IEEE 802.11 standard, it can solve connectivity issues in VANETs due to highly dynamic topology. In addition, probabilistic relay does not affect the original behavior of these routing protocols. It only changes how they deal with undelivered unicast packet. Under 10 m/s, the addition of probabilistic relay into AOMDV-PR does not give a significant improvement. Due to its multipath availability, AOMDV still can deal well under VANET environments. Its Multipath mechanism provides more route options for data packet to reach destination. If the main route is broken, it can be switched to other alternative routes. Thus, connectivity issues can be solved by the availability of multipath. However under 20–30 m/s, AOMDV-PR improves from 2–5% than AOMDV. It confirmed the contribution of probabilistic relay to deal with highly dynamic environment of VANETs. On the other hand, AODV-PR gains 3–6% than AODV. Instead of having a number of alternative path as in AOMDV, AODV only provides unipath for each destination. So, it cannot hold well under frequently changed topology. Thus obviously, AODV has lower PDR than AOMDV.

In our second evaluation Fig. 6, it is very interesting that the addition of probabilistic relay does not add more routing overhead in both AOMDV-PR and AODV-PR especially under highly dynamic environment, 20–30 m/s. we do not consider beacon message as a routing overhead. AODV produces more routing overhead to maintain broken links. On the other hand, AODV-PR has retransmission control to deal with undelivered unicast packet. Thus, data packets are confirmed to be delivered before the broken link detected. Obviously, both AOMDV and AOMDV-PR have generated more control packets than AODV and AODV-PR due to their multipath construction and maintenance. However,if we focus only on the number of RREQ generated during the simulation, AOMDV and AOMDV-PR outperform AODV and AODV-PR as it shown in Fig. 7. The availability of multipath in AOMDV effectively reduces the frequent route discovery due to disconnected link than unipath of AODV under highly dynamic environments. It can switch into another path if the main path is broken during the data packet transmission.

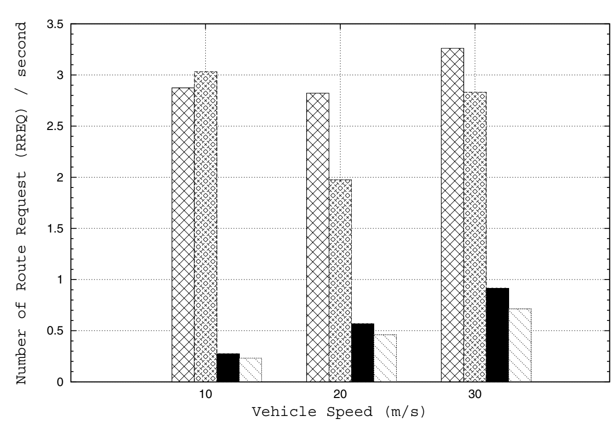

Fig. 7. Number of Route Request of Various Vehicle Mobilities

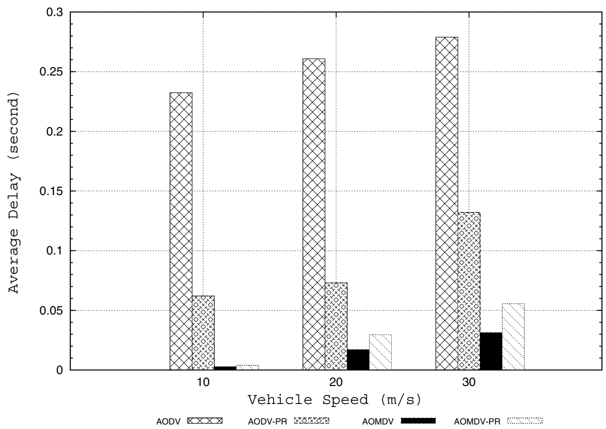

Fig. 8. Average Delay of Various Vehicle Mobilities

Fig. 8 shows the average delivery delay relative to the vehicle mobility. Probabilistic relay improves delivery delay of AODV-PR. It constanly reduced 0.17 second under any vehicle speed. Probabilistic relay allows adjacent vehicles to relay undelivered unicast packet instead of waiting for another retransmission. On the other hand, AOMDV has better delay than AOMDV-PR. Switching directly to another alternative route sometime gives an advantages than waiting for adjacent node to relay undelivered unicast packet. But the difference is very small, AOMDV-PR gained 0.01 second than AOMDV.

V. Conclusion and Future Work

In this paper, we showed that the addition of probabilistic relay into AODV and AOMDV clearly improved their performance. Both AODV-PR and AOMDV-PR outperform their original form. Probabilistic relay allows vehicle to exploit the advantages of sender diversity by leveraging adjacent vehicles to deal with retransmission of undelivered unicast packet. Moreover, probabilistic relay does not affect the original behavior of these protocols. AODV-PR significantly contributes up to 3–6% improvement in PDR under variation of vehicle speed. Probabilistic relay clearly helps to recover unsuccessful packet transmission through its unipath. On the other hand, multipath mechanism of AOMDV works enough to handle connectivity problem under low speed, 10 m/s. Its multipath mechanism provides rich route options for data packet transmission. Thus, connectivity issues can be solved by the availability of multipath. However, under high speed, 20–30 m/s, AOMDV-PR improves from 2–5% than original AOMDV. It showed the role of probabilistic relay to deal with highly dynamic environment of VANETs.

AODV-PR and AOMDV-PR have competitive result in routing overhead with their original form. In our simulation, beacon message was not considered as a routing overhead. AOMDV produces more control packets than AODV due to establishment and maintenance of its multipath. However, multipath of AOMDV generates lower RREQ than AODV during our simulation. It clearly stated that the availability of multipath in AOMDV reduces the frequent route discovery due to disconnected link under highly dynamic environments. It can switch into another path if the main path is broken. Meanwhile, AODV only has unipath to reach the destination. Thus, route discovery needs to be executed if the path is broken. In short, probabilistic relay helps routing protocols to improve their PDR while it can keep almost the same amount of routing overhead.

For the future work, we try to modify the calculation of probabilistic relay for under highly density vehicle in a city environment. Increasing the number of vehicles in the city, will also increase the number of relayed packets. Thus, it can degrade the performance of routing protocol due to congestion problem. We also want to analyze the optimum number of relayed packets due to the unsuccessful transmission. Thus, we can reduce the number of unnecessary relayed transmission.

Acknowledgment

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