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3 authors:

Sufyan T. Faraj Al-Janabi
University of Anbar

Yaseen Yaseen
University of Anbar

Bob Askwith
Liverpool John Moores University

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Sufyan T. Faraj Al-Janabi
College of Computer
University of Anbar
Ramadi, Iraq
sufyantaih@ieee.org

Yaseen Saleem Yaseen
College of Computer
University of Anbar
Ramadi, Iraq
yasenalheety@yahoo.com

Bob Askwith
School of Computing and Mathematical Sciences
Liverpool John Moores University
Liverpool, UK

Abstract—**Vehicular Ad Hoc Networks (VANETs) belong to the class of wireless communication networks known as Mobile Ad Hoc Networks (MANETs) in which vehicles represent the mobile nodes within the network. More efficient and beneficial routing techniques can be deployed in VANETs whenever the distinct properties of such networks are carefully taken into consideration in designing these techniques. In this paper, we focus on modifying and enhancing the Ad hoc On Demand Distance Vector (AODV) routing protocol to make it more convenient and suitable for VANETs. The enhanced version of AODV is called Bus AODV (BAODV). This new version reduces the end-to-end packet delay which occurs due to vehicle specific movement patterns. BAODV also can be used to enhance the passenger experience by reducing trip delays. Other metrics such as Packet Delivery Ratio (PDR) and Normalized Routing Load (NRL) overhead have been also measured through NS-2 simulation study. It has been found that they are not negatively affected due to the enhancement in end-to-end delay performance.**

Keywords- AODV; Ad hoc networks; BAODV; NS-2; routing protocols; VANET

I. INTRODUCTION

When vehicles directly communicate with each other and with road side (infrastructure), an entirely new paradigm for vehicle safety applications can be created. Even other non-safety applications can be greatly enhanced such as road and vehicle efficiency. Data transfer among vehicles is accomplished by three ways: bidirectional, single-hop and multi-hop position based. Each one of them is used for specific application. Bidirectional is a classic communication in both directions. The other two regimes are one-way communications; faster communication. In order to transmit all the vehicular information, the need to a protocol, which handles the messages transmitted and tries to avoid message collisions, will be necessary. So the Medium Access Control (MAC) layer will be responsible for that. Physical channel(s) with dedicated frequency range is used to transfer information called physical layer (abbreviated PHY). The standard which used in vehicular communication is called Dedicated Short Range Communications (DSRC) [1] and IEEE 802.11[2] between vehicles.

The importance of Vehicular Ad Hoc Networks (VANETs) has been recognized by many car manufacturers, governmental organizations, and the academic community. The Federal Communications Commission (FCC) has allocated a spectrum for VANETs. Governments and some car manufacturers, such as Toyota, BMW, and Daimler-Chrysler have launched some important projects for VANET, such as Advanced Driver Assistance Systems (ADASE2), Crash Avoidance Matrices Partnership (CAMP), CARTALK 2000, Fleet Net, and CarNet [3], [4]. VANET applications are classified into classes; for each one there is set of protocols. Without classification, development or designing a separate protocol for each application will be a nasty or difficult work.

The issue of routing is a basic issue in any type of networks. VANET is not an exception. However, efficient routing in VANETs needs to take into consideration the distinct characteristics of VANETs. Thus, this work considers the issue of designing and testing an efficient routing protocol for VANETs. The proposed protocol which we have called Bus Ad hoc On-demand Distance Vector (BAODV) protocol is an enhanced and modified version of the well-known AODV protocol. The enhancement and modification have been performed such that the new protocol will be more suitable for the environments of VANETs. NS-2 simulation has been used for evaluating the proposed protocol.

The reminder of this paper is organized as follows: Section 2 gives a brief overview of the previous work in this field. Section 3 contains a definition of the problem statement. Then, the proposed routing protocol (BAODV) design is described in Section 4. Some simulation issues are explained in Section 5. Next, the evaluation of BAODV based on NS-2 simulation is described in Section 6. Finally, Section 7 concludes the paper.

II. RELATED WORK

The challenges involved in developing a routing protocol for mobile ad-hoc network are very different and more complex than those of static wired networks. In MANETs, the routing protocol should be capable of rapidly adapting to link failures and topology changes caused by node movements. Therefore, the routing protocol should work in a distributed manner with a self-organizing capability. The goal of the routing protocol is to compute the optimal path between any source–destination pair with minimal control traffic overhead.

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This should be achieved within the constraints imposed by the ad hoc networking environment.

Ad hoc On Demand Distance Vector (AODV) is one of the most popular and widely studied ad hoc routing protocols. It was proposed by Perkins and Royer [5], and is widely considered the standard for high mobility environments. AODV has been standardized in the IETF as experimental RFC 3561. In this routing protocol when a node receives broadcast query Route Request packet (RREQ), nodes store the address of the sending node in their routing table; the record of a previous node is called backward learning. When a destination node is reached another type of routing packet is used, Route Reply (RREP) packet, then this packet is sent through a path obtained from back learning to the source.

When the RREP packet returns from the destination each node will store the previous node address to establish a forward path from source. Full duplex paths are then used to flood query packets and send reply packets. The resulting path is then maintained as long as the source uses it. Failure path will be informed to the source node to resend another query to find a new route. AODV is essentially an improved version of an earlier protocol, DSDV. The routing protocol name implies that node establishes rout only when it is necessary or important to send data. So update will be only broadcast to neighbors' node instead of entire nodes on a network. Therefore, there is no need to make source routing to entire node on a network.

Research activities in the VANET domain are becoming increasingly important for advances in multiple application fields of vehicles communication [6]. One of the most important VANET challenges is that VANET routing protocols preform variably depending on the different environments such as highway, city, and downtown area. Some important relevant works can be referenced in [7]- [12].

III. Problem Statement

The problems which have motivated us to propose this new routing protocol are related to the affect buses have on city environments. These affects come from, as mentioned in Highway Capacity Manual [13], the nature of buses which are the most common type of heavy vehicles found in such environments. For this reason, there are routing protocols designed to reduce these effects of buses in urban areas, one of them is a position-based routing protocol called Anchor-based Street and Traffic Aware Routing (A-STAR), which was designed specifically for IVCS (Inter Vehicle Communication System) in a city environment. Unique to A-STAR is the usage of information on city bus routes to identify an anchor path with high connectivity for packet delivery.

Furthermore, a project called BUSNet was performed to study the performance of MANET routing algorithms in the IVCS based on a Metropolitan Grid model (M-Grid) [14]. The work in [8] assumed that there is a regular number of buses by which street is served. Connectivity on such streets can be higher due to higher density of vehicular nodes and more stable due to regular presence of city buses. With this observation, in A-STAR weight can be assigned to each street based on the number of bus lines by which it is served, i.e. the more bus lines by which a street is served, the less weight it is assigned, and vice-versa.

In our work, the proposed routing protocol (BAODV) has been designed to choose a route with the smallest number of buses as possible. This gives two important benefits. Firstly, the new routing protocol reduces End-to-End delay in network. This modification can be considered as an issue of the network layer (routing layer). Our second enhancement reduces the number of buses on a selected route to the destination in a city environment. This enhances passenger experience and is a very desirable feature (see [15] for example). This can be considered as application layer benefit.

IV. BAODV Routing Protocol

In this section we will describe the design of our proposed routing protocol BAODV. Since BAODV is a modified version of AODV, we will focus here on the most important modification aspects of the protocol. Other aspects that are similar to AODV can be referred to in the original AODV documentation. The original AODV was not designed to work in VANET. There is a weakness in the AODV when it is applied to VANET, specifically when a node (vehicle) updates its routing table. In order to overcome this weakness; however, BAODV needs to sense about the type of vehicles, because each vehicle has specific characteristics depending on its behavior. This is the key concept in the design and operation of BAODV.

The routing table has vital information, which is used to select a route from one vehicle to a specific destination. When an update occurs in several places such as in recvRequest, recvReply method and so on in AODV.cc simulation implementation, the update must be checked to ensure that it satisfies two important conditions. The first condition is the sequence number (which is allocated on request packet and routing table or routing table and route replay whereas a newer sequence number is better). The second condition is the hop count, where a lower hop count is better. We may argue that the second condition alone is not appropriate for many city environments (especially the downtown). This is because it ignores the effect of various types of vehicles such as passenger vehicles, buses and so on. Hence, considering the lower number of hops (which means number of vehicles) on the road solely for choosing a route can be insufficient and/or unsuitable. Thus, for better and more beneficial routing, the vehicle type also has to be determined to match the vehicle to a specific behavior type.

For example, if there are two routes such that the first has six vehicles (hops) with three buses and the second has five vehicles with four buses, AODV will select the second because it contains a lower number of vehicles. However, from a practical point of view, the first route usually will be better because it contains a lower number of buses. We can only achieve this by detection different vehicle types. Thus, BAODV has been designed with assumption of the possibility of sensing of buses and also sensing other types of vehicles. This assumption is well-justified and can be achieved with minimal technological effort in VANET environments. There are four main types of packets in AODV: Hello packets, RREQ, RREP and RERR. In our proposal, we will need to modify RREP and RREQ packets via adding new parameters to its contents. The first of these refers to number of vehicles (may be passenger's car, bus, trial, trucks etc.) in a packet through traveling the packet from vehicle to vehicle. Another parameter is required to compute the number of buses through route while traveling on vehicles. After that, these collected data about a type of vehicles must be stored on each vehicle allocated on route, so there is a need to modify routing table too.

Thus, in the RREQ packet of BAODV which is transmitted from source to destination through intermediate vehicles, there is a need to additional two fields: number of vehicles in route to destination, and the second field is needed in computing the number of buses in this route. Similarly, in the RREP packet of BAODV which is transmitted from destination to the originator vehicle of RREQ through intermediate vehicles, there is also need to include two similar fields for computing the number of vehicles en-route to the source because the values in RREQ may be changed due to mobility, and computing the number of buses in this route, respectively. Additionally, for each route stored in the routing table, there is a field for the number of vehicles in this route, and another field specified for the number of buses in this route.

All this information must be simulated in real time rather than loaded before the simulation. Therefore, we must collect this information in a careful way by taking into account the movement of vehicles, type of these vehicles, which vehicles allocated on each road, and so on to all vehicles and their routing tables.

V. Simulation Issues

When simulating a VANET, we must simulate both the network and mobility attributes of the scenario. These two aspects are provided by two independent simulator entities that enable researchers to build a topology and produce a trace of vehicle movements using a mobility simulator. The mobility model will significantly affect simulation results. Thus, the mobility model must be as close to reality as possible. In VANETs, nodes must only move on streets while on MANETs the Random mobility model is the most popular model.

There are many simulators to simulate the network communication while vehicles' movement such as Network Simulator 2 (NS-2), OPNET Modeler, GloMoSim, and OMNeT++. NS-2 is widely used in the research community. It has grown via contributions from the research community as well as DARPA and commercial software developers such as Xerox and is available for free. The primary reason for choosing NS-2 was its support of a multi-hop wireless environment. Secondly, most of the studies cited in the literature review have used NS-2 as their simulation environment. This facilitates the comparison of our results with the performance results of the standard AODV [16]. NS-2 is an open-source object-oriented discrete event-driven simulator designed specifically for research in computer communication networks. NS-2 can be applied on a very large number of applications, protocols, network types, network elements and traffic models [17].

There are several simulation software environments to generate trace files that reflect vehicles' movements, such as VanetMobisim [18], the open source SUMO (Simulation of Urban Mobility) project [19], MOVE (Mobility model generator for Vehicular networks) [20] which rapidly generates realistic mobility models for VANET simulation, and CityMob v.2 [21]. CityMob v.2 is an NS-2 compatible mobility model generator proposed for using in VANETs. It is based on the Downtown mobility model. The Downtown Route System was formally introduced in [22]. In our work CityMob v.2 has been used to generate a mobility patterns for vehicles.

VI. Evaluation of BAODV

There are several metrics to evaluate routing protocols. These metrics can be used to measure the performance and activities that are running in NS-2 simulation to facilitate the choice of the best routing protocol or to adjust the protocol parameters. The three metrics used in this research are:

- *Packet Delivery Ratio (PDR):* The packet delivery ratio in this simulation is defined as the ratio between the number of packets sent by constant bit rate (CBR) sources (in application layer) and the number of received packets by the CBR sink at destination, as follows [23]:

$$PDR = \sum CBR_{PR} by CBR_{\sin ks} / \sum CBR_{PS} by CBR_{sources} \quad (6)$$

Where PDR is Packet Delivery Ratio, "CBR_{PR} by CBR_{Sinks}" is CBR Packets Received by CBR Sinks, and "CBR_{PS} by $CBR_{Sources}$" is CBR Packets Sent by CBR Sources. The above equation describes a percentage of the packets which reaches the destination.

- *End-to-End (E2E) delay of data packets:* There are some delays that happen in packet transition to a receiver. These are mainly caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at MAC layer, and the propagation and transfer times. For each received packet, the average of E2E delay can be defined as the time difference between every CBR packet sent and received divided by the total time difference of CBR packets. The lower the average E2E delay is the better application performance [24]:

$$E2E = \sum (CBR_{PRT} - CBRP_{PST}) / \sum CBR_{PR} \quad (7)$$

Where E2E is End to End delay, CBR_{PRT} is a time of CBR Packets Received by CBR Sinks. CBR_{PST} is a time of Packets Sent by CBR Sources, and CBR_{PR} is the number for the packets that had been received.

- *Normalized Routing Load (NRL):* The ratio of control packets sent by network to all received data packets called normalized routing load. It is a measurement of protocol efficiency. Low value of normalized routing load shows a more efficient protocol [24].

$$NRL = \sum RTR_{SP} / \sum CBR_{RP} \quad (8)$$

Where NRL is Normalized Routing Load overhead, RTR_{SP} are Routing packets send by routing protocol, and CBR_{RP} are all packets received by CBR sources.

The performed simulation study of BAODV and comparing it to AODV has been carried out to satisfy two major concerns: the first has been to run simulation to measure the performance of the two protocols based on changing the speed of vehicles, i.e. to measure the movement effects. Thus, we have measured the behavior of the two routing protocols with respect to End-to-End (E2E) delay, Packet Delivery Ratio (PDR), and Normalized Routing Load (NRL). The second goal of simulation has been to measure the behavior of the two routing protocols based on changing the number of vehicles. In this case, we have measured PDR and E2E metrics in order to see how the proposed routing protocol performs when changing in a number of vehicles.

A-Speed of vehicles scenarios

In this category of scenarios, experimental results have proved that the E2E delay performance of BAODV will be usually better than AODV because it is better tuned to eliminate the delay behavior of buses. Indeed, our measurements have shown that both of the PDR and NRL has not been negatively affected by the modification of proposed routing protocol BAODV.

In these scenario files, we have chosen the simulation of 60 nodes in 1000*1000 square meters area; the distance between streets equals to 20 meters; and the number of lanes per streets has been assumed to be 2. We have also assumed a Point of Interest area of (300.0, 400.0; 600.0, 700.0). The probability of vehicles to enter the POI area has been assumed to be 50%. The minimum distance between nodes has been assumed to be 5m. The probability ratio of facing the red semaphores while a vehicle is moving towards its destination has been assumed to 0.5. That mean each vehicle may face red semaphore with probability equal to 50%. The maximum time a node can be stopped at each semaphore has been assumed as 20 seconds. Table 1 shows the most important simulation parameters.

Simulation results for the effect of speed change on E2E delay are shown in Figure 1. From this figure, we notice that at very low speeds (traffic congestion), there is no obvious advantage for BAODV compared to AODV. However, as speed begins to increase in the downtown area, BAODV will outperform AODV most of the time. This is because the network makes benefit from determining the types of vehicles. At higher speeds (such as in 60-70 km/h), we notice that the E2E delay for two routing protocols is decreased and they show a similar performance. This is expected because in this latter case all vehicles types will have relatively high speeds and the negative effects caused by buses will significantly be reduced (i.e. buses behave just like other small cars).

We have also manipulated some of the simulation parameters in order to have better idea about the behavior of the two routing protocols. In general, we have concluded that the proposed routing protocol has better performance than the original one in most of the normal situations of downtowns and cities. For example, when we have decreased the maximum connections between nodes, BAODV shows much better E2E delay characteristics. On the other side, when we have increased the ratio of buses to other cars more than the typical ratio, the BAODV performance in terms of the E2E delay has decreased.

Other metrics such as NRL and PDR have been measured too. The simulation results for these metrics show no significant negative effects on these metrics after the enhancement of the E2E delay metric, as shown in figures 2 and 3, respectively.

TABLE 1. SIMULATION PARAMETERS

Parameter	Value
Network simulator	NS-2 2.34
Channel type	Wireless channel
Network interface model	Phy/WirelessPhy
MAC protocol	IEEE 802.11
Data (traffic) type	CBR
Antenna model	Omni Antenna
Mobility model	Downtown model
Simulation area	1000*1000
Simulation time	300s
Data packet size	512
Propagation model	Two ray Ground
Number of nodes	60
Maximum speed	30, 40, 50, 60 and 70 km/h
Routing protocol	BAODV and AODV
Queue type	PriQueue
MAC rate	2 mbits/s
Network interface queue	DropTail/priQueue
Hello interval	2 seconds
Tx range	250 meters
Node placement	Random

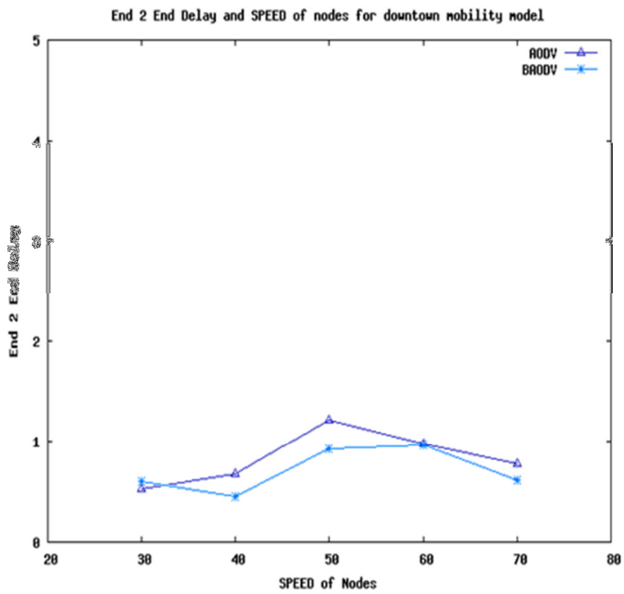

Figure 1. Effect of change of vehicles speeds on E2E delay

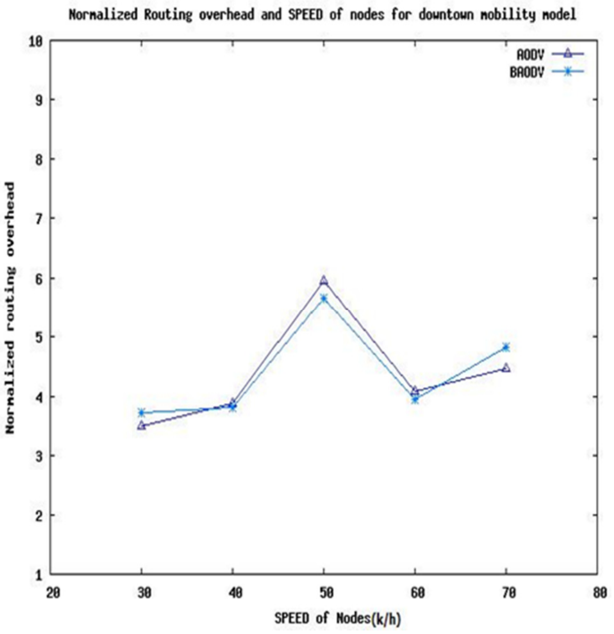

Figure 2. Effect of change of vehicles speeds on NRL

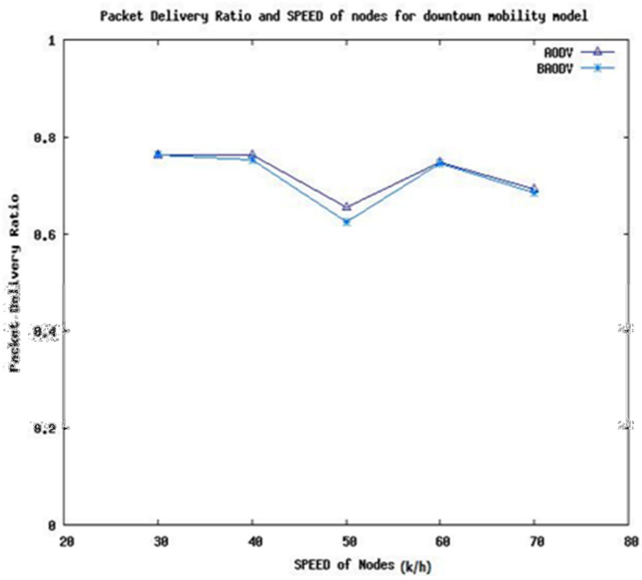

Figure 3. Effect of change of vehicle speeds on PDR

B-Number of vehicles scenarios

In this set of scenarios, we have similar assumptions to that mentioned previously. However, the speeds of vehicles have been kept the same in all scenarios here with a range from 50-70 km/h. The number of vehicles has been varied as (40, 50, 60, 70 and 80). In addition, it is important here to manipulate the process of random generation of buses in each scenario such that the expected number of buses, for example, when simulating 40 vehicles is usually less than that when simulating 50 vehicles, and so on.

Simulation results for the effect number of vehicles on the E2E delay are shown in Figure 4. From this figure, we can notice that the BAODV outperforms the AODV in all simulation instances. Simulation results for the effect of the number of vehicles on PDR also have no significant negative effects for the BAODV case similarly as in the speed scenarios.

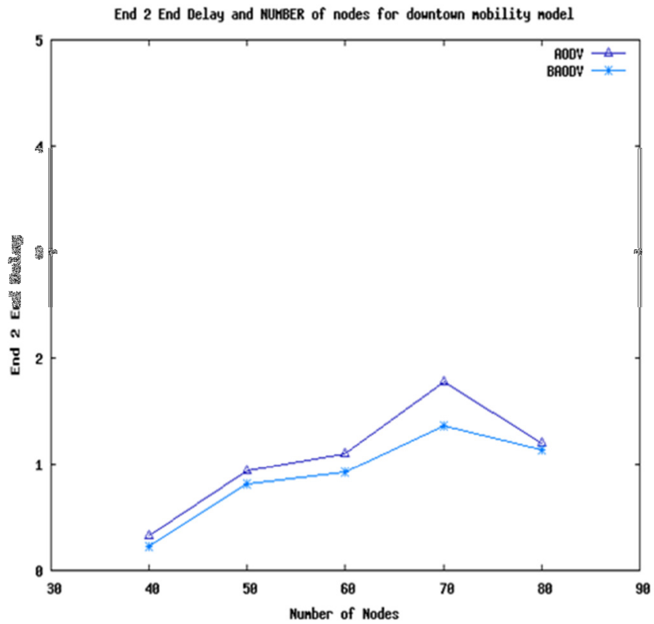

Figure 4. Effect of change of the number of vehicles on the E2E delay

C-Performance advantage in the application layer

Another enhancement benefit goes toward providing comfort travel application for passengers. This enhancement can be considered as application enhancement. It is a direct consequence of the key concept in BAODV design and operation. Since, the main modification on AODV required to produce BAODV is the inclusion of the possibility of sensing the types of vehicles in the road firstly and making benefit of this information in the routing layer secondly, the same information on vehicle types can also be used in the application layer.

BAODV is designed to have a tendency to usually choose the route with a smaller number of buses for packet delivery. This can also be of benefit for drivers to choose the best route to reach their destinations. The best route might be neither the shortest route nor the route with minimum number of vehicles; it can be the route with smaller number of buses. This can be true especially in downtown areas (or at least this information on the number of buses in relative to the number of other vehicles can be useful on making such decisions by drivers).

Finally, it is important to note that the proposed routing protocol (BAODV) may not be appropriate in all circumstances since it is basically designed for downtowns and similar city areas. For example, if we consider an environment that has no buses, such as villages or some places outside the border of cities, in these situations the original AODV will have efficiency performance better than BAODV. A possible solution for this problem is to include the two routing protocols in network layer and enabling the system automatically to choose the most appropriate of them according to the driving area. This opens the compatibility issue between the two routing protocols messages so that they can understand each other.

VII. Conclusion

In this work we have examined the most important properties of our proposed routing protocol called BAODV using NS-2 simulation. The simulation study has shown that BAODV outperforms the traditional AODV especially in terms of E2E delay in downtown and other similar city areas. E2E delay enhancement is very important in VANETs, especially for notification and warning messages. The proposed protocol can also enable an improved route to be recommended for drivers to avoid congestion (mainly caused by buses). Future work can be done by focusing on particular environment and trying to include further enhancements in different directions. Some of these directions can be including the effects of other types of vehicles (not only buses), testing BAODV with other generators, and supporting BAODV towards geographical routing.

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