A New Adaptive Probabilistic Broadcast Protocol for Vehicular Networks

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3 AUTHORS:

Ahmed Yassin Al-Dubai

Edinburgh Napier University

Mustafa Bani Khalaf

Hashemite University

Wajeb Gharibi

Jazan University

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Ahmed Y. Al-Dubai, *Mustafa Bani Khalaf, **Wajeb Gharibi and ***Jamal Ouenniche
School of Computing, Edinburgh Napier University
10 Colinton Road, Edinburgh, EH10 5DT, U.K, Email: a.al-dubai@napier.ac.uk
*Faculty of Science and IT, Jadara University, Jordan, Email: mbanikhalaf@jadara.edu.jo
**College of Computer Science & Information Systems, Jazan University, Jazan, Saudi Arabia.
P. O. Box 4425 Arrawabi, Unit #1, Jazan 82822-6694, KSA, Email: gharibi@jazanu.edu.sa
***Business School, University of Edinburgh, EH8 9JS, UK, Email: Jamal.Ouenniche@ed.ac.uk

Abstract. In VANETs, there are many applications that use broadcast communication as a fundamental operational tool, in disseminating information of interest to other road users under the umbrella of both safety and entertainment applications. Recently, the probabilistic broadcasting scheme is suggested as an efficient broadcast approach. Although a number of probabilistic schemes found in the literature, they still suffer from a high level of rebroadcast redundancy, which often leads to the Broadcast Storm Problem (BSP). Thus, in this paper a new efficient probabilistic broadcast scheme is developed, to target both achieving a high delivery ratio and reducing broadcast redundancy. Using simulation experiment, we compared the performance of the proposed scheme against the recent well known probabilistic schemes and our results confirm the superiority of our scheme over existing schemes in terms of key performance metrics, namely Reachability (RE) and Saved Rebroadcast (SR).

Keywords—ITS; VANETs; Broadcast.

I. INTRODUCTION

Vehicular ad hoc networks (VANETs) play a key role in the Intelligent Transportation Systems (ITS) architecture. The main aim of using VANETs applications is to increase road safety, and provide more business-oriented and entertainment applications. It has been reported in [1] that about 60% of rear-end collisions can be prevented if car drivers have a 0.5 second additional warning time. Thus, the design of new protocols, by utilizing VANETs to disseminate warning messages to a large number of vehicles spread across sparse geographical areas is vital as well as challenging.

Dedicated Short Range Communication (DSRC) generations technology was developed over the last decade to meet the new requirements of VANETs safety and non-safety applications. DSRC is also known as WAVE (Wireless Access in Vehicular Environments) [5] or IEEE 802.11p [6]. Communications between vehicles in VANETs can be accomplished by two methods, depending on the mechanisms of using DSRC. The first method is communication between vehicles, in which each vehicle sends messages to a specific vehicle on the road. The second method is communication between road side and any vehicle on the road. These two methods of communications within VANETs are also called Vehicle-Vehicle (V2V) and Vehicle-Roadside V2R communications respectively [5, 7, 8]. *Broadcast communication* has been the cornerstone of many VANETs applications to send information messages from either V2R, or from V2V on the roads. For instance, a given road-side station can broadcast a message about an accident at a specific position on the road. The first time each vehicle receives this message, rebroadcasts it to its neighbours, in *a multi-hop* fashion, except the one it has received the message from. The vehicles may respond to this broadcast message, by detouring to another road, and thus avoid the scene-of-accident congestion. The primitive method of implementing the broadcast service is *'flooding'*. In this approach, each vehicle floods the network, with the message that has been received, in order to guarantee that each vehicle has been successfully reached. The effect of using this method does not have a significant impact on a network, which has a limited number of mobile nodes. However, in large and scalable networks such as VANETs, the side effect of using flooding, can dramatically decrease its performance. This is because there are large number of redundant broadcasted messages, collisions in transmission between vehicles and the competition on the shared wireless medium. This phenomenon is well known in MANETs and so-called *Broadcast Storm Problem (BSP)* [9]. The methods used to solve BSP are divided into four schemes [10]: (i) probabilistic-based (ii) flooding-based, (iii) area-based (divided into location-based and distance-based) and (iv), neighbour- knowledge-based. Those schemes have widely been studied within the MANETs' environment, and there is much ongoing effort to mitigate the impact of BSP [11, 12, 13, 14, 15]. However, this problem is still in its infancy in VANETs [17,18]. In an effort to fill this gap, we propose a new solution to alleviate the BSP, which we describe later, and explore its performance in terms of message *Reachability* and *Saved Rebroadcast.* The remainder of this paper is organized as follows: Section 2 reviews broadcast in VANETs. In Section 3, we present our proposed protocol. Then in Section 4, we analyze, using simulation experiments the broadcast based probabilistic scheme with different system parameters. Section 5 concludes this study.

II. RELATED WORK

In [4] the authors explored the degrading effect of BSP in VANETs, by using single-lane and multi-lanes highway scenarios. The study also suggests three probabilistic and timer-based broadcast schemes, and evaluates their performance in terms of message delay, packet loss rate and overhead. The first scheme is slotted 1-persistence, in which each vehicle rebroadcasts the message with probability 1. The second scheme is slotted p-persistence scheme, which requires all vehicles to rebroadcast with a pre-determine fixed-value forwarding probability *p*. Value of *p* is selected to be equal to 0.5 to maximise the network performance. However, this scheme still suffers from large redundant retransmission and can be improved by using multiple values of *p* [11, 13]. Finally, Weighted P-Persistence (WPP) scheme performed the rebroadcast operation by allowing each vehicle to rebroadcast with a probability equals to the ratio between the sender, receiver and transmission range. WPP [4] is inefficient to handle broadcast in a sparse area and to select a proper value of *p* to rebroadcast in a dens area. For these three schemes each vehicle should buffer the message for a certain time period before broadcasting the message. Urban Multi-hop Broadcast (UMB) protocol has been proposed for VANETs in [3] to address the BSP, hidden node problem and reliability of multi-hop broadcasting. This protocol achieves a high success rate under a high packet load and different network densities. However, installing repeaters and using black-burst signals require additional hardware and power consumption. A fully Ad-hoc Multi-hop Broadcast protocol (AMB) [2] was proposed as an extension for UMB to avoid using repeaters at intersections. AMB uses a directional broadcast method to assign rebroadcast function to the furthest vehicle, and intersection broadcast method to handle rebroadcasting message at the intersections without depending on repeaters.

In [12] the authors propose broadcast schemes that handle the BSP by limiting the broadcast direction of emergency information, to only surrounding the source vehicle. However, the authors do not quantify the impact of problems caused by broadcast and do not evaluate them in specific measure such as Saved Rebroadcast. In [15] a broadcast scheme for inter-vehicle communication is proposed, with minimum end-to-end delay and number of transmission time. This scheme is based on the position, direction and speed of transmitting and receiving vehicles. It minimizes the BSP by ignoring the retransmission by the vehicles that do not cover new vehicles. In fact, although a number of probabilistic schemes found in the literature as discussed above, they still suffer from a high level of rebroadcast redundancy, which often leads to the BSP Problem (BSP). In this paper, we propose a new Adaptive Weighted Probabilistic Persistence Scheme (AWPP) that takes the advantage of shortcomings of the existing traditional WPP scheme. We also conducted a wide range of extensive simulation analysis for a number of important performance metrics including Reachability and Saved-Rebroadcast over varying network operating conditions such as map density and vehicles mobility, which do not exist in the recent studies.

III. The Adaptive Weighted Probabilistic Persistence Scheme (AWPP)

Having surveyed the related works, we came to the conclusion that an efficient broadcast protocol for VANETs has to be capable of striking a balance between message-reachability and Saved Rebroadcast. The message should reach all vehicles in the road, with a few retransmissions. To achieve this goal, we develop in this study AWPP scheme and investigate its performance in the VANETs context.

In the conventional WPP, each vehicle upon receiving a packet rebroadcasts with probability p_{ji}, which can be calculated as follows:

$$P_{ij} = \frac{D_{ij}}{R} \qquad (1)$$

D_{ij} is the relative distance between nodes i and j, and R is the average transmission range. As part of WPPs' rules, vehicles should wait a random time before rebroadcasting to make sure that they rebroadcast with low probability, if the message has been received from multiple sources. Vehicles with the same distance from the source have the same chance to rebroadcast. Therefore, using this scheme in high dense VANETs leads to BSP. On the other hand, a receiver vehicle could be close to the source vehicle, and in the same time in sparse VANETs. This means that the receiver vehicle has a very low probability to rebroadcast and this leads to poor reachability. Thus an appropriate technique to adjust the re-forwarding probability should be designed.

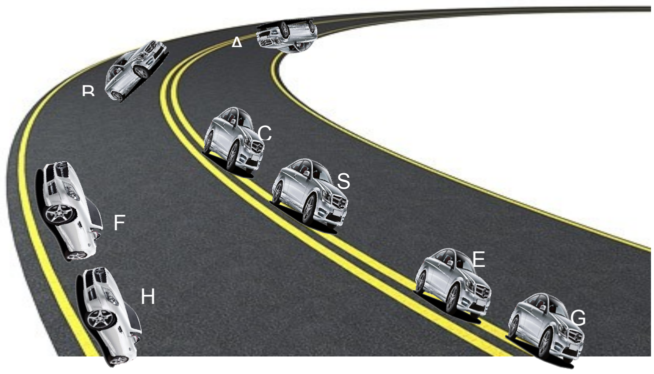

Figure 1: Illustrates the shortcomings of WPP scheme.

Figure 1 illustrates the above two scenario. For example, assume that vehicle S broadcasts a message within 250 m transmission range. The distance D between vehicle S and vehicles C, E, F, G and H are 5 m, 100m, 100m, 125m and 125m respectively. By using equation 1 the rebroadcast probability for each vehicle is 0.02, 0.4, 0.4, 0.5 and 0.5 respectively. We observe that the rebroadcast process from C will die out, and does not reach vehicles A and B. Rebroadcasting from vehicles E, F, G and H will result in more duplicated messages. As discussed above, the inefficient broadcast methods can cause connection gabs between vehicles, and increase probability of collision between vehicles that have the same distance in a dense VANETs. Therefore in this study we propose a generic probabilistic method that dynamically adjusts the re-forwarding probability per vehicle, and takes into consideration the local density for each vehicle as shown in Figure 2. To estimate the local density for the network, we collect the neighbourhood information by using 'HELLO' packet to construct a 1-hop neighbour list at each vehicle.

Adaptive Weighted Probabilistic Persistence Scheme (AWPP)

Begin
{
Step1: Upon reception of a broadcast message *msg* at a Vehicle V_r for the first time.
Step2: Get the distance **d** between Vehicle sender V_s and V_r.
Step3: Get Number of neighbours N_n at V_r.
Step4: Get the network average number of neighbours N_{avg}.
Step5: IF d< r/2 and N_n> N_{avg} THEN
V_r is located at a dense area
V_r is near to V_s and small broadcast coverage
V_r rebroadcasts with a low Probability P = P_{low}
Go to step 7
Step6: IF d> r/2 and N_n< N_{avg} THEN
V_r is located at a sparse area
V_r is far from V_s and large broadcast coverage
V_r rebroadcasts with a high Probability P = P_{high}
Go to step 7
Step7: IF ((Random::uniform(0.0, 1.0)<= P)
Forward(*msg*)
Else
Free(*msg*)
}
End

Figure 2: logical steps of AWPP scheme.

For a given map topology scenario, if N is the number of vehicles in the network, and X_i be the number of neighbours at a vehicle V_i at a particular time instant, N_{avg} is the network average number of neighbours can be defined by the following relation:

$$N_{avg}=\frac{\sum_{i=1}^{N} X_i}{N} \tag{2}$$

Each node periodically broadcasts 'HELLO' packet every second for 1-hop to collect the value of X_i, as it is recommended in [6]. This value indicates whether the V_i is in a dense or in a sparse area. For instance, when the number of vehicles which surround V_i at a particular time instant is above N_{avg}, that means V_i is in a dense area. Otherwise, V_i is in a sparse area. After that, the rebroadcast decision can be made independently by each node. Figure 2 illustrated the logical steps of AWPP. Due to the resources and time limitation we opted to conduct extensive simulation experiments to find an approximate value of N_{avg}. Table 1 shows different values of N_{avg} under different road conditions.

TABLE 1
SUMMARY OF THE EXPECTED AVERAGE NUMBER OF NEIGHBOURS FOR DIFFERENT NUMBER OF VEHICLES AND ROADS

Number of vehicles	Road length	N_{avg}
25	1x1km	7
50	1x1km	12
100	1x1km	25
200	2x2km	39
250	2x2km	45

The AWPP logically partition the road into two parts, i.e., dense and sparse location using N_{avg} threshold value. Each vehicle at each location has a specific different value of probability *p*.

The forwarding probability at dense areas is adjusted as follows:

$$P_{low} = \frac{D_{ij}}{R} - \frac{N_{avg}}{X_i}, N_{avg} < X_i \tag{3}$$

And for the sparse areas value of P_{high}, it is adjusted as follows:

$$P_{high}= \frac{D_{ij}}{R} + \frac{X_i}{N_{avg}}, N_{avg} > X_i \tag{4}$$

In some cases the value P could be less than zero or over than one. In case less than zero this means that a vehicle very closes to the sender and in a very dense area. So through coding we adjusted the value of P to zero.

TABLE 2
POSSIBLE VALUES OF P WITH DIFFERENT DISTANCES AND NEIGHBOURS

N_{avg}	X_i	D_{ij}	Value of P
7	13	20	$P_{low} = 0$
10	7	100	$P_{high} = 1$
9	2	50	$P_{high} = 0.42$

But in case over one, this means a vehicle is very far from the sender and in a very sparse area. So the value of P is adjusted to one. Table 2 shows possible different values of P. Each vehicle that receives the broadcast message should buffer it, initializes a counter and wait for a delay time $T_{(WAIT\_TIME)}$. The vehicle should select equation 3 to rebroadcast, if it receives the same message more than one time within T_{max} period. Otherwise, equation 4 should be selected. In this paper, we propose the following formula to calculate the rebroadcast delay:

$$T_{(WAIT\_TIME)} = T_{max} * T_0 \tag{5}$$

$$T_0 = \begin{cases} (1-\frac{D_{ij}}{R})*(\frac{X_i}{N_{avg}}) & , X_i > N_{avg} \\ (1-\frac{D_{ij}}{R})*(\frac{N_{avg}}{X_i}) & N_{avg} < X_i \end{cases} \tag{6}$$

T_0 represents the relationship between vehicle density and its distance from the sender. Notice that the value of T_{max} is generated uniformly between [0, 2ms] as recommended in [20]. This means that a vehicle with more neighbours rebroadcast with long time period, whilst a short time assigns for the vehicles with few neighbours.

IV. PERFORMANCE ANALYSIS

This section presents extensively different simulation experiments, to explore the probabilistic scheme behaviour under different conditions. In this study we have used NS-2.34 [16], and Manhattan Grid Model which already has been used in previous studies. Vehicles have been placed on an area of 2x2 km and for 15 minutes.

TABLE 3
SUMMARY OF THE PARAMETERS

Parameters	Value
Number of vehicles	25,50,100,150 vehicles
Number of lanes	2 lanes
Area	1000 m x 1000 m
Velocity	20, 40, 60, 80 km/h
Pause time	0, 10, 20, 40, 60/s
Transmission range	250 m
Mobility model	Manhattan Grid Model
Simulation time	15/m

For this study, we divided the simulation area into 2 horizontal streets and 2 vertical streets with 4 intersections. At each intersection vehicles with a certain probability can turn left or right. In this scenario a turn probability parameter is chosen to be 0.5. Each street has two lanes and vehicles can move in both sides. Vehicles are engaged in transmitting data within a reliable transmission range of 250 meter, which is an approximate standard range for DSRC [19]. Traffic density was varied from low to high traffic by changing the number of vehicles on the road. For example, during non-rush hours and rush hours traffic the number of vehicles was 25v/km, 100v/km respectively. To simulate vehicles velocity in a city environment we have run different experiments with different velocities. For instance, vehicles perhaps move with a velocity of 60 km/h due to the street max speed limit, or with a low velocity of 30 km/h, due to heavy traffic conditions. Simulation experiments have been conducted using our scheme, AWPP, against the conventional WPP [4] and Simple Flooding (SF) protocols. The simulation parameters are summarized in Table3. The experimental results indicate how different values of rebroadcasting probability of P can have a significant effect, on a number of redundant messages and transmission coverage areas. In the first experiment, different scenarios of traffic conditions have been assessed, by varying the number of vehicles from 10 to 100/km. We analysed the probabilistic scheme in terms of two important metrics [9, 12] which are defined as below:

Saved Rebroadcast (SR): assume r is a number of messages received by V_r. If s is the number of messages that are sent by V_s, then the Saved Rebroadcast can be defined as follows:

$$SR = 1 - \frac{s}{r} \tag{6}$$

Reachability (RE): assume N is a number of vehicles in the network, and r is a number of messages that are received by V_r., then Reachability can be defined as follows:

$$R = \frac{r}{N} \tag{7}$$

Effect of vehicles density.

Figures 3 and 4 display the performance results obtained when comparing AWPP against WPP and SF protocols using networks with different vehicles density. The number of vehicles was varied from 25v/km to 100v/km, with a minimum speed of 20km/h and a maximum speed of 60km/h. ***Saved Rebroadcast (SR)*** refers to the protocol ability to reduce the number of duplicated messages**.** Figure 5 shows SR in SF, AWPP and WPP for various vehicular densities. The performance of AWPP protocol outperforms both SF and WPP protocol in both dense and sparse areas. For example, when the number of vehicles is 100v/km, the amount of SR is 73%, 39% and 0%, for AWPP, WPP and SF respectively. However, when the number of vehicles is 10v/km, the amount of SR is equal 31%, 15% and 0 % respectively. Consequently, this is strong evidence that AWPP can be applied over a wide range of vehicular densities. ***Reachability (RE)*** refers to the proportion of vehicles that received the message, to the total number of vehicles on the network. Figure 6 shows that the percentage of RE increases for the three schemes, with respective increment of vehicular density. However, after a certain level of density, i.e., 70 v/km the RE tends to be equal to 100%. This means that AWPP succeed in achieving the same level of flooding reachability as the dense VANETs. In the traffic-non-congested VANETs, SF performs slight better than AWPP and WPP.

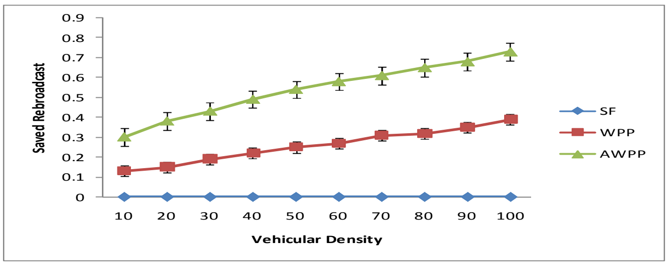

Figure 3: The SR of three broadcast protocols vs vehicular density.

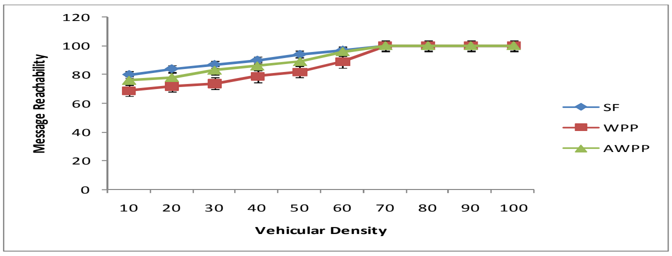

Figure 4: The R of three broadcast protocols vs vehicular density.

Effect of vehicles velocity

Figures 5 and 6 depict the results of running SF and WPP against AWPP. The network density is set at 70v/km while we considered the velocity ranges between 30km/h and 80km/h to study the behaviour of AWPP under different velocities. Figure 5 illustrates the SR performance results of the three protocols. Again, AWPP can significantly improve SR at different velocities compared to SF and WPP.

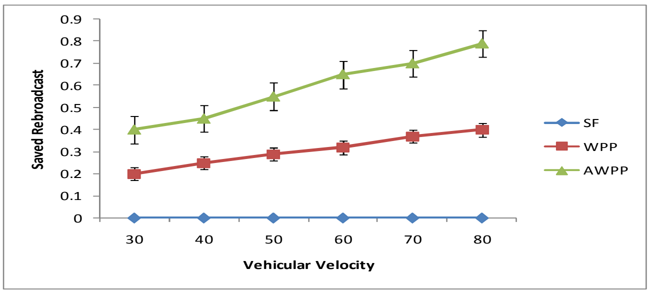

Figure 5: The SR of three broadcast protocols vs vehicular velocity.

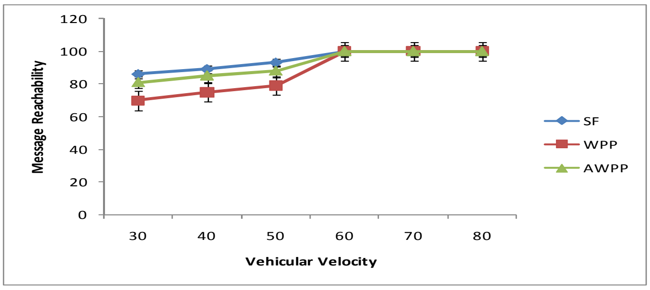

Figure 6: The R of three broadcast protocols vs vehicular velocity.

SR increases as the velocity increases. For instance, SR increases from 40% to 68% compared to WPP when the velocity increases from 30km/h to 80km/h. SR for BF is equal zero for all velocities, because every vehicle rebroadcasts the broadcast message. AWPP has a clear noticeable performance over SF and WPP. For instance, AWPP can achieve a high amount of SR, approximately over 50% and 100% compared to WPP and SF, respectively. Figure 6 shows that the total network RE increases when the velocity increase. This behaviour is noticeable for the AWPP, WPP and SF protocols. There is no doubt that SF has the best value of RE, which almost equal 100%. On other hand, AWPP performs better than WPP, and achieves the same level of RE at some velocity points. For example, in relatively very fast moving network, i.e., over 60km/h our protocol has the same value of RE as SF and WPP.

V. CONCLUSIONS AND FUTURE DIRECTIONS

In this paper we have proposed a new AWPP broadcast protocol, to mitigate the broadcast storm problem. We have conducted simulation experiments and our results confirm the superiority of our AWPP scheme over the well-known exiting counterparts. Furthermore, AWPP has clear advantages over flooding as it saves up to beyond 60%, and 25% compared with SF and WPP schemes.. We anticipate that our results have practical significance for VANETs designers to develop broadcast based applications with prescribed degrees of coverage and connectivity.

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