Reducing Message Loss in DSRC Networks using Dynamic Distribution of Safety Messages over EDCA Access Categories

Mohammad A. Alsmirat, Saleh Yousef Al-Rifai, and Belal H. Sababha

***Abstract*—The use of vehicular networks for collision avoidance increased significantly in the last decade. In particular, governments are employing DSRC-based communication for this purpose. One of the main challenges for DSRC-based vehicular networks is congestion control. Many solutions are proposed in the literature to solve this problem. Recently, EDCA different access categories have been utilized to reduce network congestion by distributing messages over different access categories. This prioritizes messages over each other which reduces collisions in the network. Unfortunately, there is no current solution to dynamically find the best message distribution over the EDCA access categories. In this paper, we propose an easy and dynamic solution to control congestion by finding the best message distribution over EDCA access categories. Results demonstrate that the proposed dynamic solution reduces congestion effectively especially with larger networks.**

***Index Terms*—Access Categories, DSRC, Dynamic Message Distribution, EDCA, 802.11p.**

I. Introduction

According to the global status report on road safety 2013 [1] that was published by the Wold Health Organization (WHO), 1.24 million people die each year on the roads of 182 countries. Of these people, 59% are young adults aged between 15 and 44 years. In Europe, 47000 fatalities occur yearly because of road accidents [2]. In the USA, according to the National Highway Traffic Safety Administration (NHTSA) reports [3], more than 30,000 Americans are killed by traffic accidents every year. These facts make improving vehicle safety and vehicle collision avoidance a top priority.

USA department of transportation (USDOT) [4] and the European Commission [5] are employing vehicle to vehicle (V2V) communication to build a framework for an intelligent transportation system that helps drivers avoid crashes. In particular, they are using a technology called Dedicated Short Range Communication (DSRC) that is built over 802.11p wifi standard. 802.11p is a variation of the 802.11e standard that supports message broadcasting natively. It also supports quality of service by applying the Enhanced Distributed Channel Access (EDCA) protocol with some minor changes. With EDCA, data traffic is categorized into four different access categories (AC). EDCA assigns different priorities to these four categories. The basic idea in DSRC-based networks is to make each vehicle on the road, announce its location, speed, direction, and other information to all surrounding vehicles periodically. This announcement is usually called the Basic Safety Message (BSM). BSMs are usually broadcasted every 100 ms. Other vehicles that receive these BSMs use crash avoidance applications to analyze these messages and warn their drivers if there is a possibility of an accident. Examples of crash avoidance applications are: Emergency Brake Light Warning, Forward Collision Warning, Intersection Movement Assist, Blind Spot and Lane Change Warning, Do not pass Warning, and Control Loss Warning [6].

The crash avoidance application accuracy depends greatly on the accuracy of the known locations of the surrounding remote vehicles (RV). Each RV location is updated every time the host vehicle (HV) receives a message from that RV. One of the main problems in this system is how to guarantee the reception of the broadcast messages. If a message is lost (because of a packet collision for example), the last updated location of the RV becomes old. This may lead to incorrect warnings produced by the safety applications.

Many algorithms have been proposed in the literature [7]–[13] to solve the problem of packet collision in DSRC-based networks. These works have utilized many approaches to solve the problem. In this work, we employ and enhance on the approach utilized in [13] because it is the most easy approach to be integrated with the current standards. The basic idea here is to allow a vehicle to send its packets over its different ACs alternately. By doing this, packet collision should be reduced in the network [13]. But the question here is how to distribute the packets over the different ACs so that the packet collision is minimized.

In this paper, we propose a dynamic algorithm that finds the best distribution of the packets over the available access categories in such a way that keeps the packet loss in the network minimized. The algorithm runs in each vehicle separately (no collaboration is needed between the vehicles) and adapts the packet distribution that the vehicle uses online according to the vehicle surrounding environment. The algorithm basic idea is to allow each vehicle to try different packet distributions and keep using the one that minimizes packet loss over the air.

The proposed algorithm has been evaluated using NS3 [14] . We simulated a realistic highway like vehicle traffic scenarios with different congestion levels using SUMO [15]. We studied the performance of the algorithm using packet error ratio and the average packet inter-arrival time gap. The results show that the proposed algorithm affectively enhances the network performance in terms of both used metrics, especially with vehicular networks that experience higher

Manuscript received July 30, 2015.
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traffic congestion.

The rest of this paper is organized as follows. Section II provides background information. Section III discusses the related work in details. Next to that, the evaluation methodology is summarized in Section IV. Section V presents the proposed work and Section VI presents the main results.

II. Background

A. 802.11p

802.11p is an 802.11 standard amendment that came out in 2010 to add wireless access support in vehicular environment and it is now integrated in the 2012 802.11 standard. One of the main changes that came with 802.11p is to allow a station to transmit data outside the context of a Basic Service Set (BSS). 802.11p also supports quality of service by deploying Enhanced Distribution Channel Access (EDCA) with some minor changes. With EDCA, data traffic is categorized into four different access categories (ACs). EDCA assigns different priorities to these four categories. Different priorities are implemented using the following EDCA parameters: Arbitration Inter Frame Space (AIFS), Minimum Contention Window (CW_{min}), Maximum Contention Window (CW_{max}), and Transmission Opportunity Time (TXOP). The default values of the EDCA parameters are shown in Table I.

In 802.11p, packet communication works in broadcast mode. In this mode, there is no multiple packet transmissions within the TXOP interval. Moreover, stations do not send acknowledgment packets when a data packet is received. Furthermore, a station backoffs only one time.

TABLE I: EDCA default parameters values (in time slots)

AC	CW_{min}	CW_{max}	AIFSN
AC0 (Background)	15	1023	9
AC1 (Best Effort)	15	1023	6
AC2 (Video)	7	15	3
AC3 (Voice)	3	7	2

B. Dedicated Short Range Communication (DSRC)

DSRC is a short-range wireless communication capability that is built over 802.11p wireless standard. DSRC allows data transmissions that make safety applications in V2V communication-based systems work. As stated in [16], the Federal Communications Commission (FCC) allocated 75 MHz of spectrum in the 5.9 GHz band to be used by Intelligent Transportation System (ITS) vehicle safety applications. DSRC, in combined with a simple GPS system, provides an effective and low cost solution that provides the vehicle driver an awareness of the existence of similarly equipped vehicles around him. Each vehicle uses its GPS system to determine its location, speed, acceleration and heading. Beside GPS information, the vehicle acquires some vehicle control information such as transmission state, brake status, and steering wheel angle.

III. Related Work

In this section, we will discuss the most related work to this paper. In [13] the authors used access category (AC) virtual division and isolation to reduce packet loss. Virtual division classifies the messages into 3 classes, based on some distribution (AC1:AC2:AC3), and sends them over three different EDCA ACs. For example, the distribution can be 4:2:4. This means that 40% of packets are sent on AC1, 20% on AC2, and 40% on AC3. AC isolation guarantees that no collisions happen between different AC with different priorities. To achieve the isolation, they used the values shown in Table II for CW_{min} and $AIFSN$.

TABLE II: Suggested values of EDCA parameters (in time slots) to achieve Virtual Division [13]

AC	CW_{min}	AIFSN
AC1 (Low Priority)	15	14
AC2 (Medium Priority)	7	6
AC3 (Hight Priority)	3	2

To find the optimal distribution of data packets over the three ACs, they design an off-line heuristic tool that searches all the possible combinations of packet distributions. The tool uses an estimated (not actual) packet error rate (PER) to find the best distribution. The estimated PER calculation depends only on two factors. The first factor is the data-load size. The second factor is the PER that is calculated when sending all data traffic over a single AC using simulation. The three PER values of the three ACs are then aggregated to find the overall estimated PER. The tool ignores the number of vehicles in the network, the packet sending distribution, and other nonlinear dynamic network conditions such as the signal power path-loss. Based on this off-line tool, they find that the ratio 4:2:4 is the best packets distribution.

IV. Simulation Environment and Evaluation Methodology

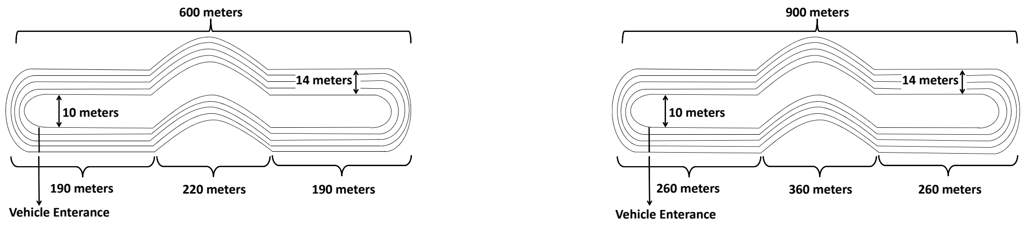
In order to simulate the network, evaluate its performance, and varify our assumptions, we use SUMO [15] and NS3 [14]. SUMO is an open source vehicle traffic simulator. It helps creating roads and intersections and simulate the vehicle traffics over them. A log of the simulation can be exported and used as mobility specifications with other simulators such as NS3. NS3 is a discrete-event network simulator. NS3 implements developed and realistic network modules. NS3 simulates 802.11p which make it suitable to simulate vehicle to vehicle communication.

A. Test Tracks

We created two test tracks using SUMO. The details of the test tracks are as follow.

- Track 1. It consists of two parallel roads as shown in Figure 1a. The two roads are connected with the curves at both ends to keep the simulated vehicles inside the track for the whole simulation time. The length of each road is 600 meters and they are 14 meters wide. There are 4 lanes in each road. In all scenarios, car length is assumed to be 5 meters.
- Track 2: This track is shown in Figure 1b. It is the same as Track 1 except the fact that it is longer. It is 900 meters in length.

We use the previous two tracks to simulate 3 mobile vehicular network scenarios.



(a) (b)

Fig. 1: Specification of Test Tracks used in Experiments. (a) Track 1 (b) Track 2

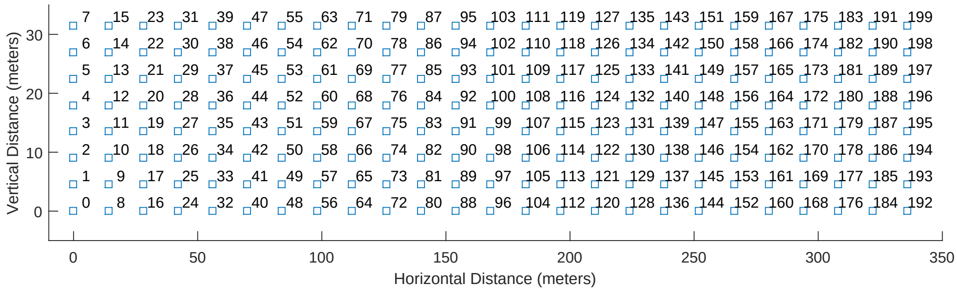


Fig. 2: Vehicle Placement in the Grid Scenario

TABLE III: The Simulation Parameters

Parameters	Values
SIFS	32 μs
Slot Time	13 μs
Message Inter sending time	100 ms
Simulation time	120 s
Number of nodes	100, 200, 300
Transmission power	18 dpm
Propagation loss model	Three Log Distance and Nakagami with NS3 default parameters
Mobility model	according to SUMO
EDCA parameters	As shown in Table II

- Scenario 1. It has 100 vehicles distributed equally over the 4 lanes on the road. The distance between each two vehicles on the same lane is 10 meters.
- Scenario 2. Same as Scenario 1 but with 200 vehicles.
- Scenario 3 has 300 vehicles with 8 meters gap between vehicles on the same lane.

To verify our assumptions, we use a grid like network, in which we simulate a vehicular network with stationary 200 vehicles arranged as the grid shown in Figure 2. The squares represent the vehicles and the numbers shown beside each of them are the vehicle numbers.

In general, we simulate a V2V communication network that uses 802.11p as its MAC. Each vehicle in the network broadcasts a BSM every 100 milliseconds that contains it location (latitude and longitude), speed, direction, and acceleration. The BSMs are distributed according to some distribution over three AC. We left the fourth one for emergency cases. Table III contains the parameters that we used in our experiments

B. Performance Metrics

Throughout this paper, we use the following performance metrics.

1) Sliding Window Packet Error Ratio (sliding window PER): Packet Error Ratio (PER) is the ratio of the received packets to the number of sent packets in a time interval. PER is usually calculated every 1 second. Each vehicle gives a sequence number to each packet it sends. The receiving vehicle recognizes the sequence numbers and the sender of the packets it receives. The deference between the sequence numbers of the first and the last packets received in a second from a single sender is assumed to be the total number of packets sent by that sender in that second. The receiver then calculates PER for that sender by dividing the number of missed packets (packets with sequence numbers that are skipped) by the total number of packets sent by that sender. Now sliding window PER is always calculated as the average of the last N seconds where N is the sliding window size. In this paper, we use sliding window size of 5. To get a single point that represents sliding window PER for an experiment, the sliding window PER values can be averaged over time.

2) Average Packet Error Ratio (average PER): the receiver calculates PER for each sender in every second and group the PER values in bins based on the distance of the sender from the receiver. The grouped PER values are then averages. In this paper, we use bin size of 20 meters. This means that the first group should contain the PER values for vehicles which are up to 20 meters away of the receiver, second group should contain the PER values for vehicles which are from 20 to 40 meters away and so on.

3) Inter-packet Gap (IPG): is the average time difference between the received packets from a specific sender.

ISBN: 978-988-14047-2-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

V. The Proposed Work

The basic idea that we employ in this work is to distribute data packets over different EDCA ACs to reduce packet collision over the air. In this work, we seek to find a dynamic algorithm that finds the best distribution of the packets over the different access categories in such a way that keeps the packet collision in the network minimized. Different vehicles may have different surrounding environment conditions. This would require the algorithm to run on each vehicle separately and adapt the packet distribution, that it would use, on-line according to the vehicle surrounding environment.

A. *Preliminary Results*

In [13], the authors concluded, based on an off-line tool, that the packet distribution 4:2:4 (which means to send 4 packets over AC1, 2 packets over AC2, and 4 packets over AC3) is the best packet distribution. We ran some NS3 simulation experiments to verify their findings using the grid network shown in Figure 2.

We used sliding window PER calculated at vehicle 10 for BSM messages sent by vehicle 20. Sliding window PER results of running the simulation using different message distributions are shown in Figure 3. As the results state, the distribution 4:2:4 is not always the best distribution.

In our search for the best distribution, we started by studying the behavior of the network, in terms of PER, under different message distribution trends. Mainly, we study the distributions where we assign more packets for low priority ACs and where we assign more packets for the high priority ACs. We ran simulations to study the impact of using these distributions on the network. We, again, used the grid network shown in Figure 2. We choose 200 vehicles because, with this network size, the network starts to become moderately congested. The vehicles are also not moving to eliminate any mobility impact that may affect the experiments. We ran the simulation using the following packet distributions: 2:3:5, 5:3:2, 6:3:1, 1:3:6, 3:3:4, and 4:3:3. Figures 4a and 4b show the results of sliding window PER for vehicle 133 receiving from vehicle 161 and for vehicle 95 receiving from vehicle 110 respectively. These results are just shown as examples. We choose these vehicles because they are about in the middle of the network so they receive packets form almost all other vehicles in the network. By studying and analyzing the results in these figures carefully, we noticed the following observations.

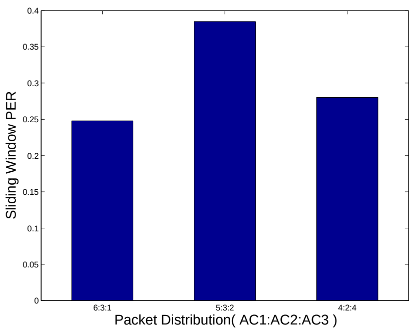
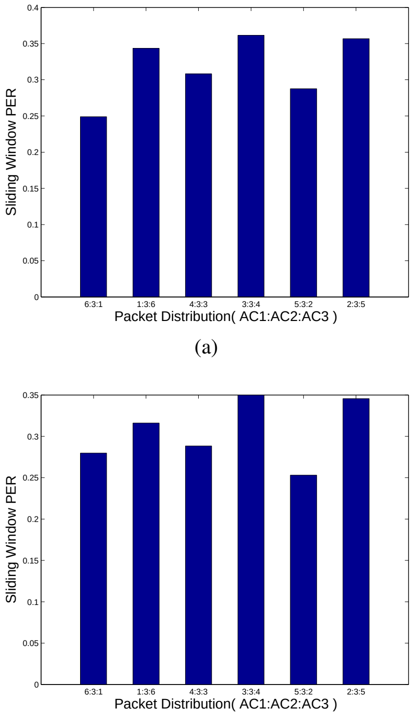


Fig. 3: Impact of using different packet distribution on the sliding window PER in the Grid network. Vehicle 10 receiving from vehicle 20



(a) (b)

Fig. 4: Impact of using different packet distributions on the sliding window PER in the Grid network. (a) vehicle 133 receiving from vehicle 161 (b) vehicle 95 receiving from vehicle 110

- The best distribution is not the same for all vehicles. This is obvious from the figures where we can see that in Figure 4a, the best distribution is 6:3:1 while it is 5:3:2 in Figure 4b. This is intuitive because different vehicles have different environments. This leads to the conclusion that each vehicle should decide its own distribution that may be different from other vehicles.
- There is no clear relationship between PER values and packet distributions. This means that formulating a function that represents the relationship is not trivial.
- Distributions with the trend where more packets are sent on lower priority ACs always give better results from their counterpart distributions. For example 6:3:1 always yields better results than that of 1:3:6. This is also intuitive because with more packets being sent over higher priority ACs, medium access attempts increases and the probability of packet collision over the air increases.

Based on these observations, we conclude that each vehicle should try all possible distributions and use the one that it gets the best performance with. The first step to do that is to minimize the number of different distributions that the vehicle should try. To find these distributions, we use the following rules:

1) Number of packets sent on the low AC should be higher or equal to the number of packets sent on the next higher AC. This rule follows the discussion of Figure 4.

ISBN: 978-988-14047-2-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

2) Every access category should send at least 1 packet per second. This to take the advantage of always utilizing all three ACs.

By following these rules, we get the 8 distributions that are shown in Table IV.

TABLE IV: The Distribution Table

Skewness Degree	AC1	AC2	AC3
1	4	3	3
2	4	4	2
3	5	3	2
4	5	4	1
5	6	2	2
6	6	3	1
7	7	2	1
8	8	1	1

The distributions are ordered in the table according to their skewness towered the lower priority AC. If we move down in the table, the skewness increases.

B. *The Proposed Algorithm*

Now we need an algorithm to find the best performing distribution. In this work we use a feedback from the network to measure the performance. The feedback is the average sliding window PER for all vehicles within 100 meters from the vehicle running the algorithm. The steps of the proposed algorithm are shown in Figure 5

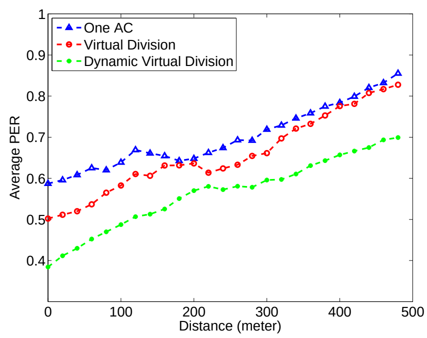
```
On each vehicle:
*Start with the initial distribution 5:3:2 and keep
using it for one second.
*Calculate the sliding window PER for all vehicles
within 100 meters range.
*Calculate the average of the PERs.
*Use the next distribution down in Table IV (increase
the skewness) (the distribution becomes 5:4:1)
At the end of each second:
*Calculate the sliding window PER for all vehicles
within 100 meters range.
*Calculate the average of the PERs.
if (the last action was increase the skewness)
    if (current PER < previous PER)
        Increase the skewness
    else if(current PER > previous PER)
        Decrease the skewness
else if (the last action was decrease skewness)
    if (current PER < previous PER)
        Decrease the skewness
    else if(current PER > previous PER)
        Increase the skewness
```

Fig. 5: The Proposed Algorithm

The vehicle starts sending packets over the different access categories with 5:3:2 as the initial distribution. At the end of the first second, sliding window PER is calculated for each vehicle within 100 meters distance and then the average of all PER values is calculated. For the next second, the distribution is changed by increasing the skewness (take next distribution down in the table). So the next distribution is 5:4:1. The algorithm always keeps track of the last action done whether it was increase or decrease the skewness. Next, the current distribution PER and the previous distribution PER are compared. If current PER is lower than the previous PER, this means that the last action that was done was successful. Consequently, it is repeated again. So if the last action was increasing the skewness, it is increased again and the distribution down of the current distribution in the table is chosen to be used in the next second. On the other hand, if the last action was decreasing the skewness, it is decreased again and the distribution above the current distribution in the table is chosen to be used in the next second. If current PER is higher than the previous PER, this means that the last action that is done was not successful. As a result, the action should be reversed. So if the last action was increasing the skewness, it is decreased and the distribution above the current distribution in the table is chosen to be used next. While if the last action was decreasing the skewness, it is increased and the distribution down the current distribution in the table is chosen to be used in the next second.

VI. Simulation Results

In this section, we show and discuss results of running the simulation of different network scenarios on different tracks. We compare the performance of the proposed solution, the *Dynamic Virtual Division*, with two other solutions. The first solution represent the standard DSRC in which all messages are sent on the background AC (we call it here *One AC*). The second solution is the one proposed in [13] and we call it here *Virtual Division*.



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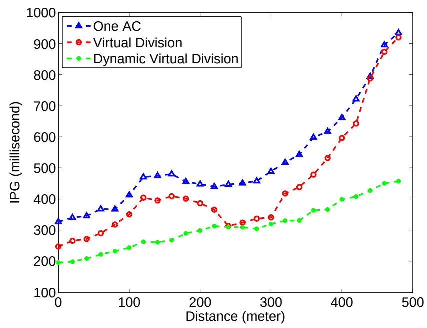


(b)

Fig. 6: Scenario 3 on Track 1. (a) average PER (b)IPG

Figure 6 shows average PER and IPG results of using scenario 3 on track 1. Results of scenarios 1 and 2 on track 1 show the same trends and thus not shown. As can be seen clearly from the figures, the proposed algorithm outperforms

ISBN: 978-988-14047-2-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

both the virtual division and the one AC in terms of both average PER and IPG for all distances. In particular, the proposed algorithm reduces PER and IPG, on average, by 20%.

Figures 7 and 8 show the average PER and IPG results of using scenario 2 and 3, respectively, on track 2. Results of scenarios 1 on track 2 show the same trends and thus not shown. As can be seen clearly from the figures, the proposed algorithm outperforms both the virtual division and the one AC solutions in terms of both average PER and IPG for most distances. In particular, the proposed algorithm reduces PER and IPG, on average, by 10% for scenario 2 and 20% for scenario 3. This means that the dynamic virtual division enhancement increases if the network experiences more congestion.

VII. Conclusion

BSM loss is the main cause for decreasing the accuracy of safety applications in DSRC-based networks. In this paper, we proposed an algorithm that reduces message loss in the network by dynamically distributing BSMs over EDCA access categories. We conducted NS3 simulations to verify our assumptions and evaluate the proposed algorithm. We have also used SUMO to generate realistic vehicular mobility models. The experiments showed that the proposed algorithm reduced BSMs loss significantly especially when the network experienced higher congestion.

References

[1] W. H. Organization, *Global status report on road safety 2013 : supporting a decade of action*. World Health Organization Geneva, 2013.

[2] European Commission. Relative positioning for collision avoidance systems. [Online]. Available: http://cordis.europa.eu/project/rcn/80566_en.html

[3] Fatality analysis reporting system (fars) encyclopedia, http://www-fars.nhtsa.dot.gov/main/index.aspx.

[4] USDOT, "Vehicle-to-vehicle (v2v) communications for safety."

[5] European Commission. Collision avoidance systems. [Online]. Available: http://cordis.europa.eu/result/rcn/45100_en.html

[6] Research and Innovative Technology Administration (RITA). Connected vehicles applications. [Online]. Available: http://www.its.dot.gov/research/v2v.htm

[7] J. B. Kenney, G. Bansal, and C. E. Rohrs, "Limeric: A linear message rate control algorithm for vehicular dsrc systems," in *Proceedings of the Eighth ACM International Workshop on Vehicular Inter-networking*, ser. VANET '11. New York, NY, USA: ACM, 2011, pp. 21–30. [Online]. Available: http://doi.acm.org/10.1145/2030698.2030702

[8] T. Tielert, D. Jiang, Q. Chen, L. Delgrossi, and H. Hartenstein, "Design methodology and evaluation of rate adaptation based congestion control for vehicle safety communications," in *2011 IEEE Vehicular Networking Conference (VNC),*, Nov 2011, pp. 116–123.

[9] T. Tielert, D. Jiang, H. Hartenstein, and L. Delgrossi, "Joint power/rate congestion control optimizing packet reception in vehicle safety communications," in *Proceeding of the Tenth ACM International Workshop on Vehicular Inter-networking, Systems, and Applications*, ser. VANET '13. New York, NY, USA: ACM, 2013, pp. 51–60. [Online]. Available: http://doi.acm.org/10.1145/2482967.2482968

[10] Y. P. Fallah, C.-L. Huang, R. Sengupta, and H. Krishnan, "Analysis of information dissemination in vehicular ad-hoc networks with application to cooperative vehicle safety systems," *IEEE T. Vehicular Technology*, vol. 60, no. 1, pp. 233–247, 2011.

[11] N. Nasiriani and Y. P. Fallah, "Performance and fairness analysis of range control algorithms in cooperative vehicle safety networks at intersections," in *LCN Workshops*, 2012, pp. 848–855.

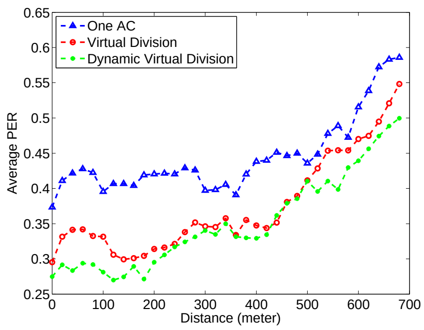
[12] N. Nasiriani, Y. P. Fallah, and H. Krishnan, "Stability analysis of congestion control schemes in vehicular ad-hoc networks," in *CCNC*, 2013, pp. 358–363.

[13] S. Sharafkandi, G. Bansal, J. Kenney, and D. Du, "Using edca to improve vehicle safety messaging," in *Vehicular Networking Conference (VNC), 2012 IEEE*, Nov 2012, pp. 70–77.

[14] Network Simulator. ns-3. [Online]. Available: https://www.nsnam.org

[15] Institute of Transportation Systems . Simulation of urban mobility (sumo). [Online]. Available: http://sumo.dlr.de

[16] "Amend rules regarding dedicated short range communications services and rules for mobile service for dedicated short range communications of intelligent transportation services, http://wireless.fcc.gov/wtb/index.htm?job=releases_page&y=2004&m=2&t=order," 2004.



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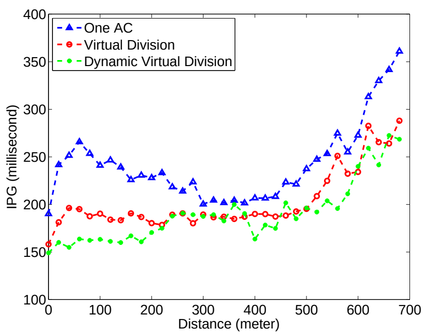
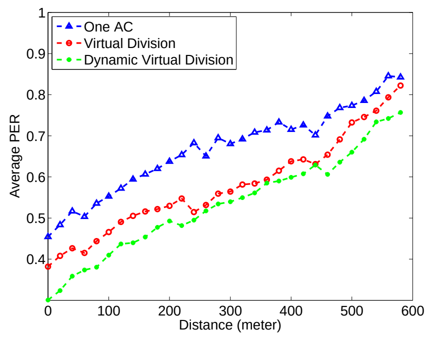


(b)

Fig. 7: 200 Nodes Scenario in Track 2. (a) PER (b) IPG



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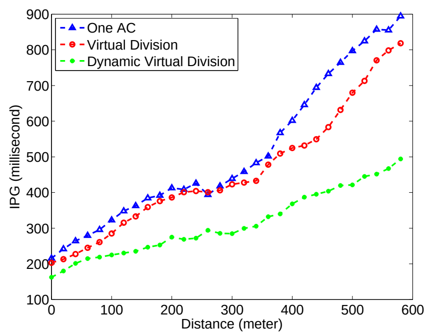

(b)

Fig. 8: 300 Nodes Scenario in Track 2. (a) PER (b)IPG