Deterministic Access for DSRC/802.11p Vehicular Safety Communication

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***Abstract*— In this work, we present the design of an efficient Deterministic medium Access (DA) for Dedicated Short-Range Communication (DSRC) vehicular safety communication over IEEE 802.11p, called Vehicular DA (VDA). VDA supports two types of safety services (emergency and routine safety messages) with different priorities and strict requirements on delay, especially for emergency safety messages. VDA processes both types of safety messages to maintain a balance between two conflicting requirements: reducing chances of packets collisions and lowering the transmission delay. To avoid long delays and high packets collisions, VDA allows vehicles to access the wireless medium at selected times with a lower contention than would otherwise be possible within two-hop neighborhood by the classical 802.11p EDCA or DCF schemes. Particularly, our scheme provides an efficient adaptive adjustment of the Contention Free Period (CFP) duration to establish a priority between emergency and routine messages. Simulations show that the proposed scheme clearly outperforms the classical DCF scheme used by 802.11p in high-offered load conditions while bounding the transmission delay of safety messages.**

Index Terms—Vehicular ad Hoc networks, contention-free, safety messages, deterministic access.

I. INTRODUCTION

Vehicular Ad hoc Networks (VANETs) is currently considered an essential technology for future road safety and telematics applications. The Federal Communications Commission (FCC) of the U.S. approved the 75MHz bandwidth at 5.850-5.925 GHz band for Intelligent Transportation Systems (ITS). This wireless spectrum is commonly known as the Dedicated Short-Range Communication (DSRC) spectrum allocated by to be used exclusively for Vehicle-Vehicle (V2V) and Vehicle-Road (V2R) communications. Devices operating in DSRC spectrum will be using IEEE 802.11p by following the WAVE operation mode [2].

DSRC spectrum is made up of seven 10 MHz wide channels as shown in Fig.1. Channel 178 is the control channel (CCH), which is the default channel for common safety communications. The two channels at the ends of the spectrum band are reserved for special uses. The rest are service channels (SCH) available for both safety and non-safety use.

There has been a vast literature [2, 8-12] on the description and evaluation of DSRC and VANET technologies. A thorough survey can be found in [8]. Existing works that use DSRC/802.11p, stress the importance of meeting the strict delay and low packet collisions requirements of safety applications, especially in high offered-load conditions and try to find adequate solutions to these issues. These works can roughly be divided into three categories: broadcast enhancement schemes [9], MAC layer solutions for backoff algorithm improvement [2] and communication rate and/or power adjustment strategies [12].

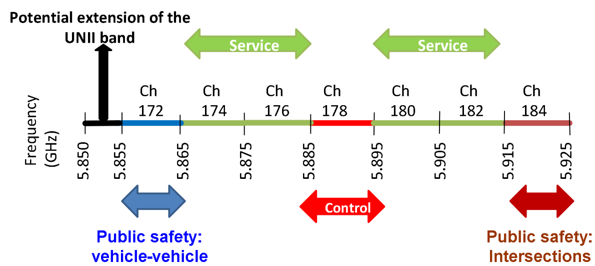

Fig.1 DSRC spectrum and channels in USA

Whereas, a few works contribute on establishing delay bounds to guarantee a short delay in IEEE 802.11p [13], our novel proposed approach for Vehicular Deterministic Access, called VDA, complements previous solutions in terms of stringent delay bounds for safety messages. To reach this goal, we propose a deterministic access for safety applications and we establish a priority between routine and emergency messages. To the best of our knowledge, we are the first to consider DA over IEEE 802.11p.

Some of the factors that affect most IEEE 802.11p performance and reliability, especially at high vehicular densities, are its channel access priority mechanism and its CSMA backoff process. Emergency safety messages requirements of low delay and low packet collisions are difficult to guarantee in dense vehicular scenarios, because of the random contention used by the traditional CSMA/CA MAC in IEEE 802.11p. Some studies tried to solve this problem by enforcing a contention-based MAC with complex schemes or by proposing modifications to the backoff algorithm [2].

The development of a robust and efficient MAC protocol will be essential to the capability of DSRC devices in enabling reliable safety applications. To achieve such a protocol, we propose enhancements to the 802.11p medium access that are inspired from the optional Mesh Deterministic Access (MDA) mechanism proposed for IEEE 802.11s [3]. This mechanism

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allows deterministic access to the medium at selected times to reduce the possibilities of collisions.

MDA aims to provide stringent MAC delay guarantees for real-time services such as voice over IP (VoIP), which is a condition that can hardly be satisfied in classical IEEE 802.11 standard. The MDA scheme [3-5] extends the IEEE 802.11 medium instantaneous reservation procedure, also known as the virtual carrier sensing (V-CS), to a more advanced reservation procedure using scheduled MDA OPportunities (MDAOPs) within a two-hop neighborhood. MDAOPs are first negotiated between neighboring nodes by exchanging broadcast setup messages, then, MDAOPs reservations are performed in multiples of a time-slot unit, during the Delivery Traffic Indication Message (DTIM) periodic interval. To limit the message broadcast signaling overhead, MDA-related messages are sent only within two-hop neighborhood.

It is worth noting though that while the MDA scheme is known to reduce to a certain extent the delay bounds, it lacks the concept of differentiating frames with different priorities. Basically, MDA provides a channel access with equal probabilities for all stations contending for the deterministic access in a distributed manner. However, equal access probabilities are not desirable among safety messages with different priories. Some recent studies as in [7] show that enforcing MDA with an efficient adjustment of the Contention Free Period (CFP) allowing differentiation between different classes of services outperforms the Enhanced Distributed Channel Access (EDCA) in terms of delay and packets loss probability for IEEE 802.11s.

Our contributions, in this paper, can be summarized as follows: (1) we first introduce and justify the adaptation of the mesh deterministic medium access named MDA to reduce packet collisions in IEEE 802.11p; (2) we improve and adapt MDA in the context of vehicular safety communication with two levels of safety services covering most of the possible safety applications; we call the new scheme VDA; (3) we derive analytically the corresponding expressions of the periodicity and VDA opportunity (VDAOP) duration in order to guarantee stringent delay bounds for safety messages; (4) we take into account the vehicles in the Carrier Sensing Range (CSR) to guarantee that none of these vehicles transmits/contends with the sender in order to ensure as high packet reception rates and as low collisions as possible; and (5) we evaluate our model compared to standard 802.11p/DCF in terms of delay, throughput and packet reception rate for both routine and emergency safety messages.

The remainder of the paper is organized as follows. Section II presents the motivation behind the integration of deterministic access in IEEE 802.11p. Section V proposes our scheme named VDA and presents a mathematical formulation of the keys parameters. Section IV evaluates the proposed solution via simulations. Finally, Section V concludes the paper.

II. MOTIVATION FOR THE USE OF DETERMINISTIC ACCESSS FOR IEEE 802.11P

When supporting safety applications over DSRC/802.11p we have to take into account strict requirements on low collisions and delays, especially for emergency messages such as Forward Collision Warning (FCW) or Electronic Emergency Break Light (EEBL) which require strict delay bounds; otherwise many envisioned future safety systems would be useless to help the driver deal with emergency situations, avoid accidents and save lives. The main points that motivate us to consider/adapt a deterministic access such MDA in IEEE 802.11p are as follows:

(1) Most of safety messages are based on direct or single hop broadcast communication among vehicles within the transmission range of one another. This is justified by the fact that if an emergency message happens, the vehicles potentially affected are those which are close to the sender. Therefore, direct communication is enough to reach potentially affected vehicles. MDA is proven [3] to be more efficient within two hops range than classical DCF/EDCF, and to guarantee a short delay.

(2) In a low-load condition, where collisions are very rare, CSMA provides lower delays than MDA since the former transmits almost instantaneously in a random time slot. In a low-load condition, MDA has a slightly higher delay than CSMA primarily due to the problem of non-contiguousness of the reserved time-slots. MDA waits longer periods before being able to transmit in specific reserved contiguous time slots. However, in high-load conditions, the delay with MDA is bounded by x*DTIM [6]; x being the maximum number of hops in a path (x=1 for broadcast messages). The delay provided by CSMA increases without any bounds with the increase of the offered load. This is because many more nodes are contending for the same channel, causing many more collisions and resulting in both longer binary exponential backoffs and more frequent MAC retransmissions. Therefore, it is interesting to investigate/adapt a deterministic access such as MDA over IEEE 802.11p to take advantage of the bounded delay guaranties its offers.

(3) Vehicle safety communication networks are entirely distributed ad hoc wireless networks, and MDA is a distributed deterministic medium access.

III. PROPOSED VEHICULAR DETERMINISTIC ACCESS SCHEME: VDA

A. *Current IEEE 802.11p Communication Scheme*

IEEE 802.11p adopts IEEE 802.11a layer specifications with minor modifications. This is a random access scheme for all vehicles located in the transmission range of the sender based on CSMA/CA. IEEE 802.11p uses CSMA/CA with EDCA as in IEEE 802.11e or DCF as in IEEE 802.11a and also uses four priorities queues with different Backoff and AIFS parameters. Nevertheless, the Backoff process with EDCA involves high probabilities of collisions, especially in high offered-load conditions.

There are two types of safety messages: emergency safety messages (M_e) and periodic beaconing (or routine: M_r) safety messages. While emergency messages happen only occasionally and require very high reliability, less collisions and short delay, routine messages are broadcasted by all vehicles at a frequency of 10-20 times per second. Routine messages contain the state of a vehicle such as its position and direction and they require low reliability and long latency compared to M_e [2]. In fact, one of the main concerns about 802.11p, is how it will perform when DSRC devices will be largely adopted, making high-offered-load conditions very likely in dense vehicular traffic situations, while having continuous routine messages beaconing sharing the medium with more urgent life-critical event-driven emergency messages.

B. Introducing VDA Process in IEEE 802.11p

VDA scheduling is based on MDA concepts; therefore, we start by introducing MDA before going into detailing our proposed scheme VDA to show what we added and modified in basic MDA.

In basic MDA [3], the time between consecutive DTIM beacon frames is divided into time slots of length $32\mu s$. The periodic broadcast of beacon frames to all radios in the same transmission range allows the synchronization of these DTIM intervals. Initially, nodes reserve the wireless medium for MDAOPs, which are reserved as multiples of time-slots during a given Contention Free Period (CFP) of a maximum access fraction (MAF= αT) of the DTIM interval T (see Fig.2). The remaining part of the DTIM interval, as illustrated in Fig. 3, is the contention period (CP) used for throughput-sensitive rather than delay sensitive data applications (it could be used in the context of VANETs for example for private service messages, M_p). Note that MDA does not support different services with different priorities and has the same behavior for all service messages in the network. The message types illustrated in Fig 2 rather refer to VDA scheme.

We characterize each MDAOP (in MDA) /VDAOP (in VDA) reservation request for message k by the triplet $< o^k, \pi^k, \delta^k >_{k\in N}$ where O^k is the VDAOP offset from the DTIM start period, Π^k is the VDAOP periodicity within the DTIM period, and δ^k is the VDAOP duration in number of time-slots. Π^k is the number of times the specified VDAOPs repeat themselves equidistantly within a DTIM interval (T). In fact, all vehicles in the same transmission range are aware of the reservation schedule due to the broadcast of VDA advertisement messages by the VDAOP requester node and the granter nodes [3].

In VDA scheduling, $\delta^k_{M_x}$ is the number of time-slots reserved for safety messages of type *x* (see Eq. 1) in each of the $\Pi^k_{M_x}$ (see Eq. 2) sub-intervals that satisfies a hard constraint on a maximal delay $D^{\max}_{M_x}$ for a maximum number of hops *m* in a path. We assume that $M_x \in \{M_e, M_r\}$ where M_x represents the safety message of type *x; x* being equal to *e* if it is an emergency message, *r* otherwise (i.e. routine message). We note that this transmission occurs after duration $AIFS_{M_x}$. To prevent exceeding the one-hop delay, the periodicity $\Pi^k_{M_x}$ in the VDA reservation request has to be sufficiently lower bounded by: $\Pi^k_{M_x} \geq T / D^{\max}_{M_x}$. For the sake of simplicity, we consider a uniform distribution of $D^{\max}_{M_x}$ over interfering links even though a better repartition may take into account the non-uniformity of traffic load over these links. Thus, the VDAOP duration (Eq. 1) and periodicity (Eq.2) are expressed as follows:

$$\delta^k_{M_x} = \left\lceil \frac{AIFS_{M_x} + \frac{L_{M_x}}{C_{M_x}}}{\tau} \right\rceil \times \frac{N_{M_x}}{D_{M_x}} \quad k \in N \text{ and} \qquad (1)$$

Where τ is the time-slot duration, L_{M_x} is the packet size (including PHY and above), C_{M_x} is the IEEE 802.11 transmission rate, N_{M_x} is the number of messages of type x and $D^{\max}_{M_x}$ is a maximal delay for message *x* computed in Eq.3.

$$\Pi^k_{M_x} = \frac{DTIM}{D^{\max}_{M_x}} = \frac{T}{D^{\max}_{M_x}} \qquad (2)$$

Fig.2 shows the details of VDA functionality in the presence of M_e and M_r in the CFP. VDA establishes priority between both safety messages and particularly, VDA prioritizes M_e over M_r. VDA also serves private messages in the CP period because such messages are not delay-sensitive. It is worth noting that the standard multi-channel switching operation in WAVE allows the CCH and SCH intervals to be different, as long as their total length is the DTIM interval. We then define the dwell-time ratio as the time-percentage between CCH and SCH interval (e.g., we could have 75% CCH Dwell and 25% SCH Dwell).

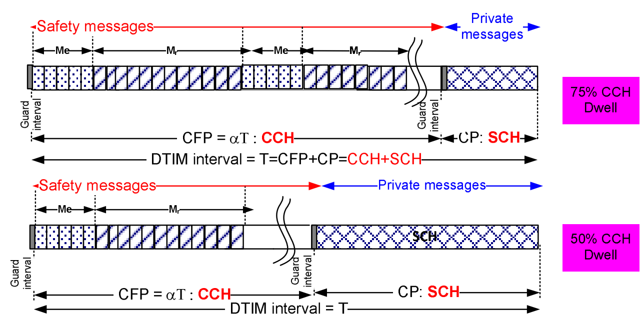

Fig.2 VDAOP schedule for emergency (M_e) and routine (M_r) messages in VDA

C. Dwell Time-Ratio in VDA

In VDA, we use **CCH=CFP** Interval (ICCH=ICFP) and **SCH=CP** Interval (ISCH=ICP). As mentioned before, WAVE allows CCH and SCH to be different, just as long as the length of the Synchronization Interval (ISynchronisation = ICCH+ISCH) which is in our case equal to DTIM interval. We assume that the DTIM is a divisor of 1sec. The ICFP and ICP can be dynamically adaptable in VDA scheme.

D. Packet Transmission Delay in VDA

We define the delay as the sum of the service and queuing delay. The service delay is the sum of the VDA scheduling delay, the $AIFS_{M_x}$ and the transmission delay of the packet. We define VDA scheduling delay as the waiting time of the next packet to be sent, for its reserved VDAOP during which it can transmit without contention. We assume that the backoff delay is negligible over a long period of time since we assume that a contention with other nodes is very rare during the reserved VDAOP. And we define the queuing delay as the time a packet waits in the transmission queue.

For emergency messages, we are in the context of 1-hop broadcast; each broadcast has π_1 packets to transmit in every DTIM interval. Then the service rate could be expressed by $S_{rate} = \frac{\pi_1}{DTIM}$ for one-hop, otherwise for m-hop $S_{rate} = \frac{\pi_m}{DTIM}$.

$$D_{M_x}^{max} = \frac{D_{M_x}}{m} \quad (3)$$

The maximal delay is denoted by $D_{M_x}^{max}$, i.e., the hard constraint on maximal delay for a maximum number of hops *m* in a path and D_{M_x} is the required delay by the safety messages M_x.

E. Probability of reception rate in VDA

The packet reception rate is defined as the ratio of the number of packets successfully received to the number of packets transmitted. The packet reception rate can be seen as the probability that all vehicles within the transmission range of the sender vehicle receive the broadcast safety message M_x successfully. We denote this probability P_{RR}.

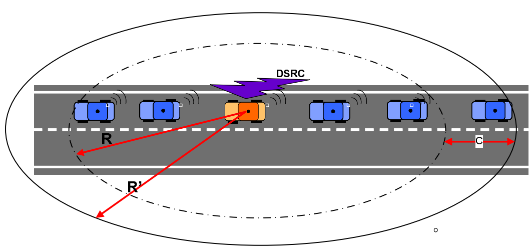

Fig.3 Scenario

We assume that vehicles are placed on the line (see Fig.3) according to Poisson process with network density β (vehicles/m) [2]. We can express the probability to have *v* vehicles per transmission range *R* as follows:

$$P(v,R) = \frac{(2\beta R)^v e^{-2\beta(R)}}{v!} \quad (4)$$

And the probability to have N_c vehicles per transmission range *R'-R* denoted by *C* as follows where R' is the carrier sensing range:

$$P(N_c,C) = \frac{(2\beta C)^{N_c} e^{-2\beta(C)}}{N_c!} \quad (5)$$

Where N_c is the number of vehicles that could contend for the same time-slots with the sender in its range R_s.

The Probability of Reception Rate (P_{RR}) in transmission range R_s can be expressed as follows:

$$P_{RR} = P(X,R_s) = P_{RR}(S,R_s) \times P_{X',R_X}(\delta_X,O_X) \times P_{X',R_X}(\delta_X,O_X) \quad (6)$$

Therefore, we describe two cases:

Case1: $N_C = 0$

$$P_{RR}(S,R_s) = P(v,R_s) \times P_{s,R_s}(\delta_s,O_s) \quad (7)$$

Where $P_{s,R}(\delta_s,O_s) \approx 1$ since the sender is the only owner of δ_s and offset O_s in its transmission range R. Since we use a deterministic access in VDA, we expect low collisions to be happening. The average number of vehicles in R is equal to $2\pi R$ while in C it is $N_c = 2\pi C$.

Case2: $N_c \neq 0$

$$P_{RR}(S,R_s) = P(v,R_s) \times P_{s,R_s}(\delta_s,O_s) \times P_{S',C_s}(\delta_s,O_s) \quad (8)$$

Where $P_{S',C_s}(\delta_s,O_s)$ is the probability that none of the vehicles S' in range C_s transmits in the time-slots allocated to the sender vehicle S in range R_s during the CFP period.

Let us define first P_0 as the probability that a vehicle has an event or a routine safety messages to transmit. In order to achieve deterministic access for vehicle S in its range R_s, we compute the probability $P_{S',C_s}(\delta_s,O_s)$, that none of the vehicles in C_s range ($\forall S' \in N_C$) transmits with number of time-slots δ_s from the offset O_s .

Proof:

To formally express $P_{S',C_s}(\delta_s,O_s)$, we applied a standard technique of proof by cases to define $P_{S',C_s}(\delta_s,O_s)$. We express first the base cases of this probability for CFP equals to 2 slots with $N_c \geq 2$ (see Equation.8) and for CFP equals to 3 slots $N_c \geq 3$ (see Equation.9).

- For CFP=2 slots; $N_c \geq 2$

$$P_{S',C_s}(\delta_s,O_s) = \frac{(1-P_0)^2}{A^2_{N_c} P_0^2 + A^1_{N_c} P_0(1-P_0) + A^0_{N_c}(1-P_0)^2} \quad (9)$$

- For CFP=3 slots; $N_c \geq 3$

$$P_{S',C_s}(\delta_s,O_s) = \frac{(1-P_0)^3}{A^3_{N_c} P_0^3 + A^2_{N_c} P_0^2(1-P_0) + A^1_{N_c} P_0(1-P_0)^2 + A^0_{N_c}(1-P_0)^3} \quad (10)$$

Then similarly,

- For CFP=K slots and $N_c \geq K$ we express the following equations:

$$P_{S',C_s}(\delta_s,O_s) = \frac{(1-P_0)^K}{\sum_{k=0}^{K} A^k_{N_c} P_0^k (1-P_0)^{K-k}} \quad (11)$$

And for $N_c \leq K$,

$$P_{S',C_s}(\delta_s,O_s) = \frac{(1-P_0)^K}{\sum_{k=0}^{N_c} A^k_{N_c} P_0^k (1-P_0)^{N_c-k} (1-P_0)^{K-N_c}} \quad (12)$$

IV. SIMULATION RESULTS

In this section, we conduct a simulation study using ns-2 to evaluate and compare the performance of our proposed scheme, i.e., VDA, with the existing scheme based on 802.11p DCF. We evaluate several metrics: 1) the end-to-end delay; 2) the outage probability; 3) the packet reception rate and 4) the average delay. The end-to-end delay is involved when safety related messages need to be relayed to other vehicles in a multi-hop manner (ex. post-crash message). The outage probability is defined as the ratio of the number of vehicles experiencing packet losses higher than the given threshold to the total number of vehicles in the VANET. The packet reception rate is rate of messages received within a one-hop range. The average delay is the average delay within a one-hop range.

A. *Simulation Configurations*

We use a topology composed of 80 vehicles with 10 vehicles in each lane in an 8 lane highway (4 lanes/ direction) The radio transmission range *r* takes one of the following values: 150m, 200m and 250m and the transmission interference R of each vehicle is 550m. Also, we fix the packet size to 1000Bytes. The parameters are presented in Table I.

Table I. System Parameters

PHY radio model	SINR
Carrier Sense Range	550m
Transmission range	150m, 200m, 250m
DTIM	32ms
Threshold packet loss	5%
α	0,68
Dwell time-ratio	50% CCH Dwell
Time slot	20 μs
MAC type	802.11 (used with DSRC)
Channel bandwidth [Mbps]	6, 9,12,24
Traffic type	CBR (UDP)
Period of message dissemination [ms]	100
Message payload size [byte]	1000
Number of vehicles	80
Speed [km/h]	100
Traffic density [veh/km/lane]	10
Number of lanes	8
Simulation time [sec]	60

B. *Results Analysis*

1) *The Delay Study*

We studied the performance of access methods DCF and VDA when transmitting data on the shared channel. We distinguish between low and high offered load conditions:

In light offered load conditions (0.05 Mbps-0.5 Mbps), where collisions are very rare, DCF access method provides lower delays, as shown in Fig. 4, since it transmits almost instantaneously in a random time slot no later than 0.68ms. In low offered load conditions, VDA waits longer periods before transmitting in a specific reserved contiguous time slots. This is because VDAOPs cannot be scheduled to start until the end of a DTIM period of 32ms. This scheduling is performed regardless of the absence of interferences and even if earlier time slots are available, since it needs contiguous available time slots to transmit packets. Therefore, the average access delay is higher with VDA compared to that of DCF when the offered load is low. However, one should note that in low offered load conditions, delays are very low both in DCF and VDA, and the extra delay introduced by VDA is very low.

In high offered load conditions (0.75Mbps-12Mbps), VDA outperforms DCF and decreases the delay by a factor of two (i.e., VDA- 0.34s and DCF-0.7s in average).

The end-to-end delay with VDA in simulations does not exceed 390ms; it is bounded by the DTIM interval, which is equal to 32ms, multiplied by the maximum number of hops in a path that is equal to 10 in our topology. Whereas the delay provided by DCF increases without any bounds with the increase of the offered load. For example, the delay with DCF reaches 725ms at 8 Mbps and it results in many more vehicles contending for the communication channel, causing many more collisions and resulting in both longer backoffs and more frequent retransmissions. The delay improvement (for all loads) is about 40% for VDA compared to DCF.

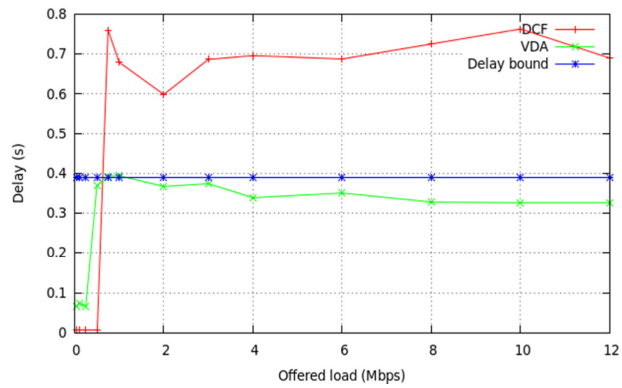

Fig.4 . The end-to-end delay of both VDA and DCF.

2) *The outage Probability Study*

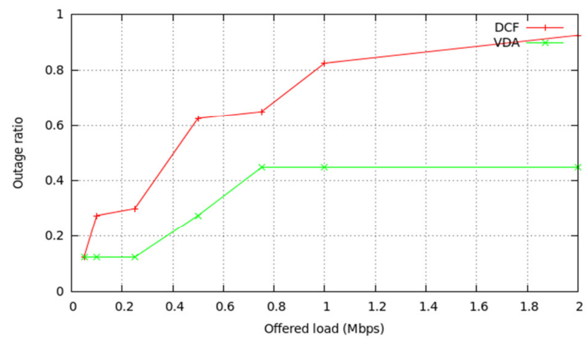

Fig.5 . The outage ratio of both VDA and DCF.

Fig.5 shows the outage for both VDA and DCF methods when varying the offered load. VDA outage is much lower since the VDA scheme allows vehicles to access the wireless medium at selected times with a lower contention than would otherwise be possible within two-hop neighborhood by the classical 802.11p DCF scheme. Therefore, VDA outage which is related directly to message losses will obviously outperform DCF method. It presents an improvement of 46% over all loads as shown in Fig.5.

In the following set of experiments we fixed the offered load to 2Mbps, and varied vehicles density in order to assess the packet reception rate and the average delay in a one-hop range when many vehicles are contending for the medium in dense vehicular scenarios both for DCF and VDA methods.

3) *The Packet Reception Rate Study*

Fig.6 clearly illustrates the difference of results between DCF and VDA methods. DCF method suffers from inevitable collisions. Therefore, it has a significant drop in reception probability. VDA enhances scheduling. The fact that VDA takes into account the vehicles in the carrier sense range to guarantee that none of them contends with the sender ensures high packet reception rates and low delays. VDA outperforms DCF by 42% in terms of reception probability. We note that in average for all densities, VDA reception probability equals 0.78 and for DCF it equals 0.44.

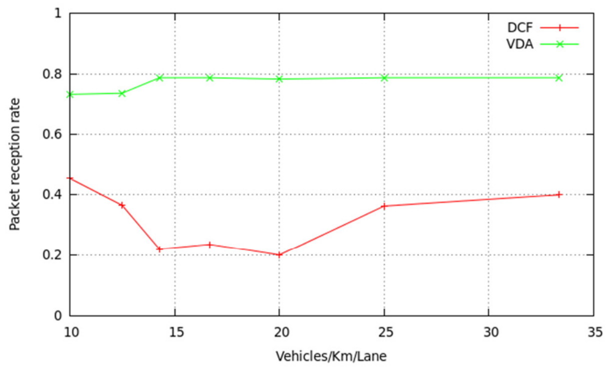

Fig.6 . The packet reception rate of both VDA and DCF.

4) The Delay of Emergency and Routine Messages Study

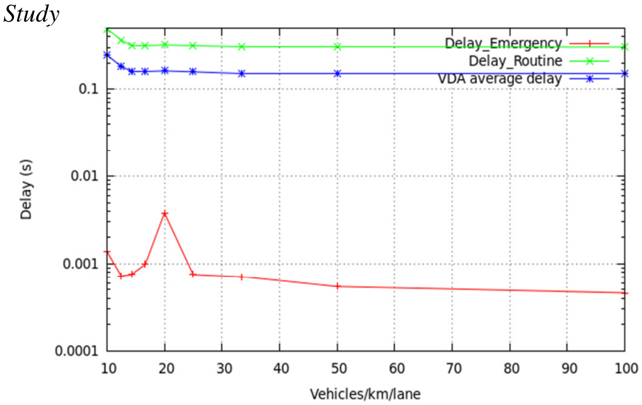

Fig.7. The delay of both emergency and routine messages in VDA scheme.

From vehicle safety point of view, it is crucial for vehicles in the highway to receive status updates (routine messages) from each neighboring vehicle in the transmission range frequently enough and in an evenly timed manner. For event-driven messages (emergency messages), the transmission delay requirements are even more strict. That is why it is very useful to have an efficient scheduling scheme such as VDA that provides lower transmission delays especially for emergency safety messages.

Fig.7 shows the delay of both emergency and routine safety messages when varying vehicle density. From the figure, we can see that, on the one hand, VDA ensures a very low delay for all densities that is less than 0.00112616s. This is very desirable since emergency messages usually involve urgent life-critical situations. On the other hand, routine messages have an average delay equal to 0.33s which is higher than the delay of emergency message but good enough for routine messages. This is the expected behavior from VDA, since the scheme prioritizes emergency messages over routine messages when scheduling VDAOPs as shown in Fig. 2.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we show how we minimize contention between high-priority safety-oriented routine or emergency traffic and non-safety application traffic using a deterministic access method over 802.11p called VDA. VDA provides bounded delays and low losses particularly for emergency messages. Using simulations, we show that the proposed approach, integrating deterministic access, outperforms DCF and achieves good performances in terms of delay and packet reception rate.

Currently, we plan to investigate a mechanism that prevents interfering vehicles not integrating VDA with 802.11p, from accessing the scheduled VDA opportunities (VDAOP) and subsequently the shared medium during reserved time-slots.

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