RMDS: Relevance-based Messages Dissemination Scheme for 802.11p VANETs

Omar Chakroun, Soumaya Cherkaoui
INTERLAB Research Laboratory, Université de Sherbrooke, Canada
{omar.chakroun, soumaya.cherkaoui}@usherbrooke.ca

***Abstract*— Vehicular ad hoc networks (VANETs) leverage communication equipment and infrastructure to improve road safety. These networks, by the rapid change of their topology and their broadcasting dissemination nature, can experience mainly two major problems; (1) the broadcasting storm and (2) network disconnection. In this paper, we focus on safety-related messages and propose a new approach to avoid the broadcasting storm and under various network load. Our scheme, called RMDS, is based on two main concepts; the critical distance and the distance of relevance. It combines an asymmetric power-range adjustment and message frequency tuning aiming to reduce network load. It integrates a new approach to prioritize locally generated messages over relayed ones according to the distance from the event originator. Simulation results confirm the effectiveness of the proposed scheme and its network performance under various traffic constraints.**

Index Terms—Vehicular ad hoc networks, distance of relevance, congestion control and avoidance.

I. INTRODUCTION AND RELATED WORK

VANETs leverage wireless communications technologies to increase vehicles' awareness of their surrounding environments. Because vehicles contend to use the same channel to exchange information, the major challenge in VANETs is ensuring that the information exchanged by vehicles gets delivered while respecting the transmission delay and reliability constraints required by targeted applications, especially safety ones.

Studies show that if the communication density is low, reliability can be ensured [13]. If the network is close to its saturation, message delivery failures cause transmission reliability to drop consequently.

Power adjustment has been studied in the early VANETs designs. Many schemes have been proposed to avoid channel saturation aiming to keep transmission reliability acceptable. They differ mainly in choosing what triggers the transmission power adjustment. Artimy et al [1] propose an adaptation scheme which is initiated based on an estimation of the number of surrounding vehicles. Caizzone et al. [2] used the same principle applied to the TDMA channel access mechanism. Torrent-Moreno et al. [3] proposed D-FPAV to control the load of periodic messages and prioritize safety-related ones. They concluded that a lower transmission power provides higher reception rates at close distance and is more relevant from a safety perspective.

Similarly to the power/range adjustment, approaches have been proposed to avoid congestion by tuning the messaging frequency. Xu et al. [4] proposed an adaptation scheme based on current vehicle velocity, transmission attempts failure and packet reception success. Elbatt et al. [5] conducted a study indicating that the probability of successful packet reception increases with a decreasing beacon generation rate. Rezaei et al. [6] proposed a novel approach with respect to the accuracy requirements. In their scheme, the adaptation phase is triggered by a maximum deviation threshold between self and neighbour estimators. Khorakhun et al. [7] proposed an adaptation scheme where vehicle increases its beacon generation rate if the channel busy time is under a specified threshold; otherwise the generation rate is decreased.

In this work, we are mainly interested in addressing congestion issues at the control channel of DSRC/802.11p [13] in cases where messages in this channel are relayed beyond one hop. Different from previous approaches, this work introduces a technique which prioritizes locally generated messages over messages generated distantly. In the scheme, priority of messages will depend not only on the safety application generating them, but will also depend on whether a message was generated locally or distantly. The rationale behind this is that messages that are generated far away, while may be still be pertinent, are most likely less critical to the receiving vehicle and thus are of less relevance. Coupled with the prioritization approach, the proposed scheme uses two techniques; (1) heavy tuning which consist in adaptively adjusting transmission range and (2) fine tuning which consists in adjusting the messaging frequency according to the distance from the message originator. To the best of our knowledge, this is the first work to propose this kind of tuning applied to safety messages priority to reduce channel access concurrency. The remainder of this paper is organized as follow; section II presents the problem formulation. Section III introduces the proposed technique, called RMDS, and its operation. Section IV presents the queuing theory-based system model. Section V gives an overview of the expected results. Finally, section V concludes the paper.

II. PROBLEM FORMULATION AND PARAMETRIC STUDY

As discussed in [8], a major challenge, caused by the channel access technique in VANETs and its related priority management technique EDCA, is the concurrency between messages to gain access to the channel. As specified in the DSRC/802.11p operation mode [13], a limited number of retransmissions cause messages to be sent in the channel regardless if it is busy or idle. This can cause frequent packet collisions. Furthermore, as the main dissemination technique in VANETs is broadcast, the problem of broadcasting storm also occurs.

In this paper, we address the problem of messages concurrency which can cause network performances to degrade, and we propose a congestion control scheme to reduce contention of safety related messages by adopting a priority-based adaptation technique. In our work, we use the following definitions:

- *Local concurrency*; is defined as the concurrency between messages having the same priority level in the same area and reporting different events. It is denoted by C_l.

- *Distant concurrency;* is defined as the concurrency between messages having the same priority level and reporting events in different areas. For example, messages generated locally and others received by multi-hop dissemination techniques. It is denoted by Cd.

- *Critical distance, Cd;* is defined as the minimum distance between the event location and the following vehicle that can give the driver the time to react and brake. It is calculated as in eq. 1 [12] where Bd is the braking distance (depends on the speed, tire/road friction coefficient (FC)), Ad the awareness distance (distance traveled during the message dissemination delay), MRD, the Mean Reaction Distance (distance traveled during the perception-reaction time usually 2 seconds).

In this paper, we are interested in reducing distant concurrency C_d by reducing distant messages priority in order to give a higher chance to locally generated messages.

$$\text{Cd} = \text{Bd} + \text{Ad} + \text{MRD} \qquad (1)\ [12]$$

$$\text{Ad} = \frac{\text{Speed}}{(3.6*10)},\ \text{MRD} = \frac{2*\text{Speed}}{3.6},\ \text{Bd} = \frac{Speed^2}{(254*\text{FC})}$$

A. Minimum Considered Range VS Maximum Achievable Range

The minimum considered range (MCR) is defined as the minimum transmission range that allows the driver to react in time. For safety purposes, *MCR* will have a value slightly higher than the Critical distance, Cd, let say by value Δ. Studies in [8] show that the Nakagami-m model is a realistic model for vehicular network. They proved also that considering the power limitation in VANETs, a maximum achievable transmission range (*MAR*) with an acceptable packet reception rate (*PRR*) is 350 meters. Therefore, we will consider it as an upper bound for the range adjustment phase.

$$\text{Cd} + \Delta \leq \text{Transmission Range} \leq 350$$

B. Messaging frequency, latency and priority

As specified in the DSRC/802.11p standard, and using the table below containing delay and messaging frequency constraints on the eight safety applications [13], we designed an adaptation phase which we called the Fine Tuning phase. In this sub-phase, an adaptation is applied to the messaging frequency based on the distance from the message originator. We considered 10 Hz as the minimum messaging frequency and a maximum messaging frequency of 50 Hz to meet the particular case of the Pre-crash sensing application.

Table I [13] summarizes some safety related messages relevant parameters such as dissemination range, the maximum allowed latency for the message to be sent, and the access class corresponding to the generated message.

TABLE I – SAFETY APPLICATION REQUIREMENTS

Application	**Messaging frequency (Hz)**	**Range (meters)**	**latency**	**AC (prio)**
Traffic signal violation	10	250	100msec	2
Curve speed warning	1	200	1000msec	2
Emergency brake lights	10	200	100msec	1
Pre-crash sensing	50	50	20msec	1
Collision/ Lane change warning	10	150	100msec	1
Left turn / Stop sign assist	10	300	100msec	1

III. SCHEME OPERATION

RMDS uses (a) a priority-triggered congestion control and avoidance, and (b) relevance-based messages dissemination as will be detailed in the next sections. The operation of RMDS uses three phases; (1) power/range adjustment based on vehicles speed and related Cd, (2) priority and relevance-based messaging frequency adaptation, and (3) a greedy forwarding dissemination phase.

A. Power/range adjustment

In this phase, a power adjustment procedure is initiated based on real-time measurements on the Packet Reception Rate (*PRR*). Using overhearing technique to detect communications in the surrounding environment, every vehicle estimates the *PRR* in its neighbourhood. Using this information and the actual maximum achievable transmission range, a vehicle can adjust its transmission range accordingly. For that particular purpose, two separated techniques are used, each of which corresponds to a type of messages of the control channel; safety (application) or routine (beacon) messages. The distinction here is based on the type of message; on one hand, for safety messages, a minimum transmission range cannot be lower than the *MCR* for safety purposes. On the other hand, for routine messages, a more severe transmission range adjustment can be tolerated.

B. Priority and relevance based messaging frequency adaptation

To the best of our knowledge, RMDS is the first adaptation scheme introducing a distinction between locally/distantly generated messages. This priority adjustment limits the effect of the *distant concurrency* as defined earlier. Consequently, the probability of messages collisions is reduced and a higher *PRR* can be achieved. In RMDS, priority adjustment can only be operated if the message has already been disseminated by at least a distance corresponding to *Cd*. This ensures that vehicles in the immediate neighbourhood are aware of the event. As a second step in this phase, a message frequency adjustment is operated based on the distance from the originator to reduce the messages dissemination impact on the channel communication density. Note that latter steps is repeated at distances multiple of *Cd* from the originator up to a 1km distance. The idea here is to get a messaging frequency adapted to the reported event magnitude. We considered 10 messages per second as a lower bound to match the standard requirements on the 100ms delay for messages delivery.

For this purpose, the relayed messages have to contain an extra field; D_{tr} which contains information on distance travelled by the message since its generation (see figure I). Thus every relay node must be able to make changes on the D_{tr} field.

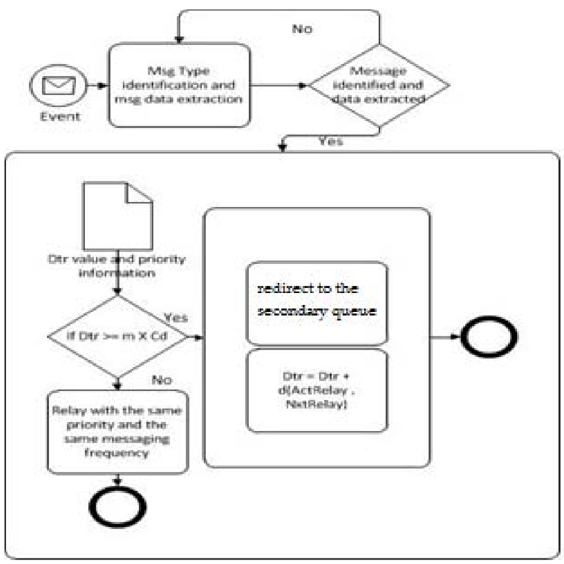


FIGURE I. – PRIORITY AND RELEVANCE MANAGEMENT IN RMDS SCHEME

C. Message dissemination phase

The dissemination is the third phase of the proposed scheme. A previous work [10] has proposed to use the farthest vehicle in an emitter vehicle range as the message forwarder, in order to ensure a low number of hops when relaying messages. Neighbouring vehicles, by implementing overhearing techniques, detect that a current message stored in their buffers is forwarded and ignore its transmission. The technique also uses the *LA* metric combining the link length and its reliability. In *RMDS*, the same dissemination scheme is used.

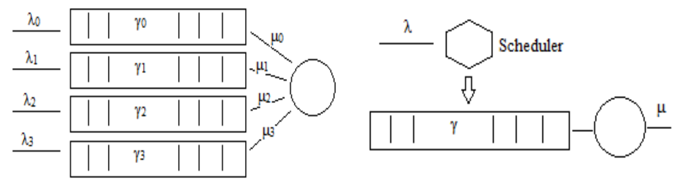
Choosing the farthest vehicle reduces the hop number and consequently the overall delay. Choosing a reliable link enhances message delivery probability. Reducing the messages priority level, when needed, reduces channel access concurrency and therefore reduces collisions probability.

IV. SYSTEM MODEL

This section presents an analytical analysis for the concurrency between locally generated safety messages and those relayed using a multi-hop technique. For safety/routine messages, the standard provides specific CW_{min}, CW_{max} and backoff values to handle different priorities.

To mimic the standard specification; a particular class of queues will be used, i.e M/M/1+D. Such queue has a Poisson arrival rate λ, an exponential service time with parameter μ with the particularity that a message will leave the system after a waiting time equal to D (patience delay i.e maximum delay for each type of message, see table I) following an exponential law with rate γ. A particular message will stay in the system (queue + server) for a maximum delay D after which it will leave the queue and will be considered as.

For simplification purposes, we are considering the use of only one queue that handles all the four messages classes and integrating an internal scheduling technique that can mimic priority handling between the four access classes (named *ACi,* i ϵ [0-3]) as illustrated in figure II. So the system can be reduced from a queuing system containing four classes of clients (λi, μi, γi, i ϵ [0-3]) to one containing only one class (λ=Σλi, μ=μi, γ=γi, i ϵ [0-3]) and integrating an internal scheduling mechanism. The main purpose of integrating a scheduler is to keep the prioritization between different types of messages. Its role is to order the queue as messages from AC_i (higher priority) will be treated before those from AC_{i+1} (lower priority).



(A) STANDARD QUEUE MODEL (B) APPROXIMATED QUEUE MODEL

FIGURE II. – SYSTEM MODEL SIMPLIFICATION

A queuing system mathematically speaking is a probabilistic space in which clients arrive at certain order. Let denote T_k the arrival time of the client C_k and s_k its needed service time. We suppose that arrivals are simple (one at a time) thus the arrival sequence (time) $\{T_k\}$ $k>=0$ is a sequence of strictly increasing random variables. We suppose also that the inter-arrivals and services suites are independent and identically distributed with the same distribution U and s respectively and that the random variables are integrable. Therefore, we have E[U]<∞ , E[s]<∞, λ:=1/E[U], μ:=1/E[s] and the working load: ρ:=λ/μ.

Let denote D_k (E[D]<∞, **γ**=1/E[D]) the random variable characterizing the delay associated to a message M_k, such that at T_k+D_k, if the message M_k is not yet processed, it leaves the system and will be considered as lost. Thus the sojourn time T_k of message M_k can be written as follow;

$$T_k = (W_k + s_k)1\{W_k<D_k\} + D_k1\{W_k>=D_k\} \quad (2)$$

Using the latter, we can derive that losing a message means that for that particular message the system proposed a delay over D_n thus the message loss probability can be written as;

$$\Pi_k := P[W_k>D_k] \quad (3)$$

Since the standard has a maximum delay for all message set at 100ms, D_k will be the same for all messages and will be noted "d" hereafter.

A. Messages loss probability derivation for one class of messages (Standard model):

Using the memory-less property associated with the exponential law leads us to use simplified Markovian models to derive the performance parameters for such a queue and give an approximation of the loss probability Π. Let denote Π_k the probability that a message quits the queue without having been served due to impatience, T_k' the time when the message M_k quit the queue. If it is not lost then this is also the time when the message enters in service thus $T_k' \in [T_k, T_k+d[$, else $T_k' = T_k+d$.

Let denote also; A_j^t, the message M_j is in service at time t, and B_j the message M_j is already processed. Thus the message M_k will be dropped if the server is busy with another message at time T_k+d. This means that the message that is already in service has been there at $T_{k-1}+d$ else it would have been dropped. Thus Π_k can be expressed as;

$$\Pi_k = \sum_{j=0}^{k-1} P\left[A_j^{T_k+d}\right] = \sum_{j=0}^{k-1} P\left[A_j^{T_k+d} \cap A_j^{T_{k-1}+d}\right]$$

$$= \sum_{j=0}^{k-1} P\left[A_j^{T_k+d} \mid A_j^{T_{k-1}+d}\right] P[A_j^{T_{k-1}+d}] \quad (4)$$

Since the service times are exponentials,

$$P[s > T_k - T_{k-1}] = P[s > U] \quad (5)$$

By replacing in the equation above and adding that $A_j^{T_{k-1}+d} \subset B_{k-1}$ and by simplification we can derive two bounds for the probability of messages loss.

$$\Pi_k \leq P[s > U]\Pi_{k-1} + P[s > U](1 - \Pi_{k-1}) \quad (6.1)$$

$$P[s > U] - P[s > U]P[s > d](1 - \Pi) \leq \Pi_k \quad (6.2)$$

Thus in stability conditions and with calculating the limits to the infinity we can derive where Π is the probability of losing a message due to reneging.

$$\frac{P[s>U]P[s>d]}{1-P[s>U]P[s<d]} \leq \Pi \leq P[s > U] \quad (7)$$

The end result for the particular case of the M/M/1+D will be obtained by replacing 8.1 and 8.2 in 7

$$P[s > U] = \lambda/_{\lambda+\mu} \quad (8.1)$$

$$P[s > d] = e^{-\mu d} \quad (8.2)$$

$$\frac{\lambda/_{\lambda+\mu} e^{-\mu d}}{1-\lambda/_{\lambda+\mu}(1-e^{-\mu d})} \leq \Pi \leq \lambda/_{\lambda+\mu} \quad (8.3)$$

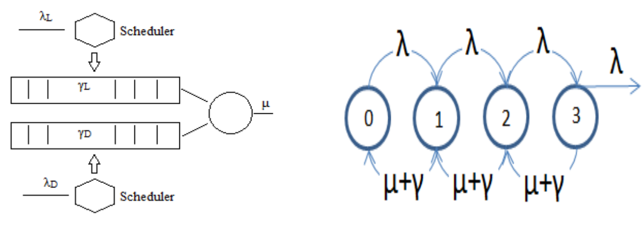
B. Performance study for two classes of messages (RMDS model):

In our scheme, we are interested in designing multiple message types having strict pre-emptive priority to give a higher chance to locally generated messages to access the channel and reduce the local/distant messages concurrency. For that purpose, we are using an extended version of the aforementioned queuing model which includes two separate queues, one of which having an absolute priority over the other; class 1 contains locally generated messages (1 hop or a certain travelled distance) and class 2 handling relayed messages as shown in figure III (a) where;

$$\begin{pmatrix} \lambda = \lambda_L + \lambda_D \\ \gamma_L = \gamma_D = \gamma \\ \mu_L = \mu_D = \mu \end{pmatrix} (9)$$

The pre-emptive priority ensures that none of the distant messages can access the server when local messages queue is not totally empty. The distinction between the two types of messages is only made internally and does not affect the arrival rate λ. As messages contained in the two queues are subjected to the same requirements, the reneging rate γ will be the same, the service rate μ as well and the reneging delay d.

Equation (9) shows the relationship between λ, λ_L, λ_D, $\gamma, \gamma_L, \gamma_D, \mu, \mu_L$, and μ_D respectively representing total arrival rate, local messages arrival rate, distant messages arrival rate, reneging rate, local messages reneging rate, distant messages reneging rate, service rate, local messages service rate, and distant messages service rate.



(A) RMDS SYSTEM MODEL (B) QUEUE INITIAL STATES

FIGURE III. – PRE-EMPTIVE PRIORITY SYSTEM MODEL

1) Mean messages count and waiting time in the system

Based on conditions in (9), we note that the system behaviour is similar to using only one class of messages and consequently, we can derive the mean number of messages in the system L_i and the mean waiting time W_i, $i \in [L,D]$ where L and D represent local and distant messages.

$$L_D = L - L_L \quad (10.1), \quad W_D = W - W_L \quad (10.2)$$

Let denote p_n the probability associated to the state n of the queue, thus using the principle of flow conservation and by recurrence, we have:

$$\lambda p_n = (\mu + \gamma) p_{n+1} \quad (10.3)$$

$$p_{nj} = \rho_j^{\ n} p_{0j}, \ \rho_j = \frac{\lambda_j}{(\mu+\gamma)}, j \in [L,D] \quad (10.4)$$

Where ρ_j designates the workload in the queue j, p_{0j} the probability associated to the initial state of queue j, λ_j the arrival rate at queue j, μ the service rate, and γ the reneging rate. Since all probabilities sum to 1, we can write

$$p_{0j} = \frac{1}{1+\sum_{n=1}^{\infty} \rho_j^{\ n}} \quad (10.5)$$

Thus;

$$L = \sum_{n=0}^{\infty} n\, p_n = p_0 \sum_{n=0}^{\infty} n\, \rho^n \quad (11.1)$$

$$L_L = \sum_{n=0}^{\infty} n\, p_{nL} = p_{0L} \sum_{n=0}^{\infty} n\, \rho_L^{\ n}, \ \rho_L = \frac{\lambda_L}{(\mu+\gamma)} \quad (11.2)$$

$$W = \frac{L}{\lambda} = \frac{p_0}{\lambda} \sum_{n=0}^{\infty} n\, \rho^n \quad (12.1)$$

$$W_L = \frac{L_L}{\lambda_L} = \frac{p_{0L}}{\lambda_L} \sum_{n=0}^{\infty} n\, \rho_L^{\ n} \quad (12.2)$$

2) Messages loss probability

In the case in which we differentiate the two types of messages M_L,M_D, the server will have one of the following states; a) it is considered empty with probability PI, b) it is serving a local message M_L or c) it is serving a distant message M_D. Note that the existence of a distant message has no impact on the local messages. Let denote P_0 the probability that no local message is present in the system. Thus, the system will serve a local message with probability $P[M_L] = 1 - P_0$. Using the latter, the probability that a distant message is admitted in service is $P_0 - PI$. Thus using Stanford conclusions [11], we can write

$$\Pi_L = 1 - \frac{1-P_0}{\rho_L} \quad (13.1), \quad \Pi_D = 1 - \frac{P_0 - PI}{\rho_D} \quad (13.2)$$

$$\rho_i = \frac{\lambda_i}{\mu}\, i\, \epsilon[L,D]$$

V. RESULTS OVERVIEW

In this section, we present theoretical results to analyse and evaluate the effectiveness of our prioritization approach compared to an operation of 802.11p where the only distinction between messages is made using their generated priority. Metrics discussed in this section are; (a) the message loss probability due to concurrency of local and distant messages, which is the main contribution of this work, (b) the mean waiting time in the system, and (c) the communication density generated locally as defined by [10] to compare the effectiveness of the adaptation scheme.

A. Simulation parameters:

We simulated multiple emergency data flows entering a relay node while varying the arrival rate and proportionality between locally/distantly generated messages to accommodate the majority of safety messages requirements. Simulations parameters are presented in Table II.

TABLE II – GLOBAL SIMULATION PARAMETERS

Parameter	**Value**
Messages arrival rate (λ)	10 - 50 msg per second
Vehicle velocity	60 - 120 km/h
Transmission power	50-350 (m)
Messages service rate (μ)	Up to 50 msg/s
Probability of inactivity	10 %
Proportionality between λ_L and λ	25 %, 50 %, 75 %

B. Results analysis:

1) Messages loss probability

In VANETs, message losses are due to two main causes; (1) multiple successive collisions which degrade network performances, (2) the concurrency caused by EDCA related backoff mechanisms that leads to channel miss-use. Here we are discussing the second category and we are making abstraction of the interferences problem in such cooperative networks. Figure IV. (A) shows the impact of prioritizing locally generated messages over those relayed from a certain distance in the particular case in which they are equally proportional. We notice that for low and medium workloads, RMDS give better results since it does not indicate message losses. On the other hand, for high workloads, message loss probability caused by RMDS exceeds the mean message loss probability when using EDCA approach by 10 percent.

Since in RMDS, locally generated messages have an absolute pre-emptive priority, they will not be delayed nor will their performances be affected by the existence or not of relayed ones. Figure IV. (B) shows such behaviour, since while varying proportionality between M_L and M_D, the probability of losing local messages remains unchanged for various proportionality values. Figure IV. (C) shows the impact of varying proportionality in the arrival rate between local M_L and distant M_D messages in high communication densities. Using higher local message proportions means that the system has to ignore distant messages processing until it processes all the local messages in the highly prioritized queue. Thus, the probability of losing M_D messages is higher when increasing M_L proportions over the total messages arrival.

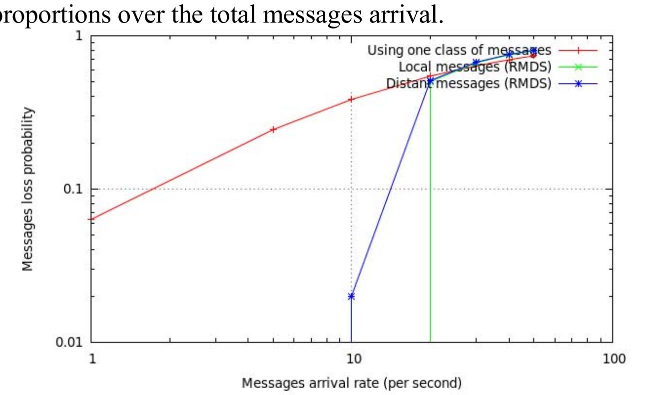


FIGURE IV. (A) – MESSAGES LOSS PROBABILITY COMPARISON USING ONE MESSAGES CLASS VS. RMDS DESIGN ($\lambda_i = 0.5\,\lambda$)

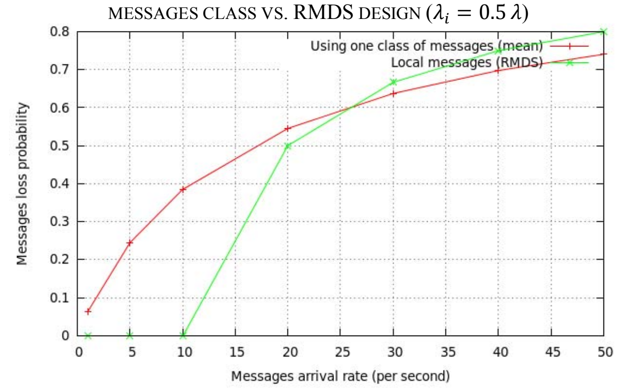


FIGURE IV. (B) – MESSAGE LOSS PROBABILITY WHEN USING ONE MESSAGES CLASS VS. LOCALLY GENERATED MESSAGES IN RMDS DESIGN WITH VARYING PROPORTIONALITY

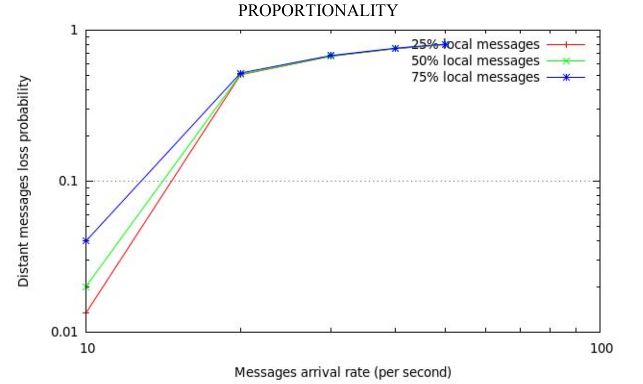


FIGURE IV. (C) – DISTANT MESSAGES LOSS PROBABILITY WHILE VARYING PROPORTIONALITY BETWEEN LOCAL/DISTANT MESSAGES

2) Mean time in the system

The mean waiting time in the system characterizes the total time spent in the queue and the server. Figure V. (A) shows the mean time spent in the system for local messages at different loads. RMDS presents better results in term of delay compared to the standard EDCA model. The 100ms standard specified delay is respected for 25% and 50% proportionalities and not for the case where 75% of the total arrivals are local messages for workloads over 70%. When using the standard approach only, the delay is exceeded for workloads over approximately 30%. Figure V. (B) shows the model behaviour for distant messages; those relayed of a distance over Cd. We can notice that the delay is only respected if the workload does not exceed 50% regardless of the impact of varying the proportionalities.

This is caused by the pre-emptive priority mechanisms, but still RMDS performs better than the standard approach. The fact of varying proportionalities has an impact on the delay and presents a means of diverting the workload from one queue to the other.

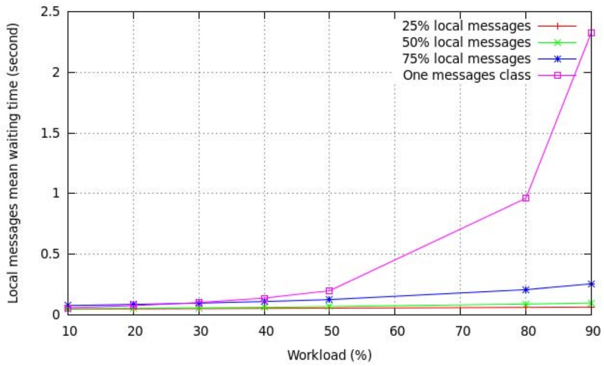


FIGURE V. (A) – LOCAL MESSAGES MEAN TIME IN THE SYSTEM

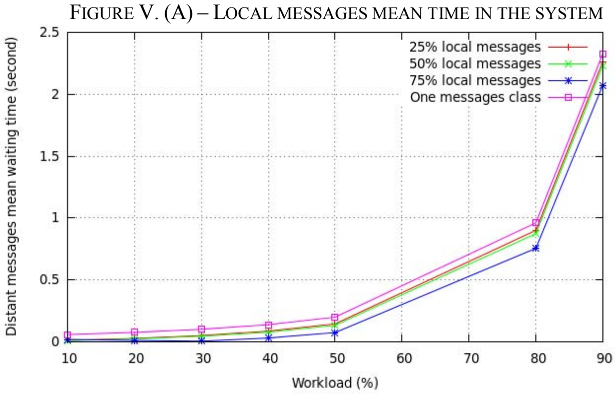


FIGURE V. (B) – DISTANT MESSAGES MEAN TIME IN THE SYSTEM

3) Communication density enhancement

As we introduced an adaptive behaviour in RMDS, we have to measure the impact of such adaptive scheme on network performances. In RMDS, two adaptation phases precede the dissemination phase. Figure V shows, in measurements made in 100 experiments, the impact of activating only one of the aforementioned adaptation phases and the effect of combining both on the measured communication density (CD). A cumulative gain up to 300 percent can be ensured thus reducing the collision probability which in turn can improve message delivery probability.

VI. CONCLUSIONS AND FUTURE WORK

In this paper, we present a relevance-based adaptation and dissemination scheme for VANETs. RMDS dynamically adapts the transmission range/messaging frequency and introduces a prioritized scheme to handle differently locally generated message versus relayed ones. Using queuing theory, we showed that RMDS outperforms the traditional and we believe that the adjustment techniques introduced by RMDS can effectively reduce channel congestion when messages need to be relayed among vehicles beyond one hop. A future work will be to conduct extensive simulations of vehicular scenarios especially in highly congested situations, to confirm the effectiveness of our scheme compared to the results found with the theoretical model.

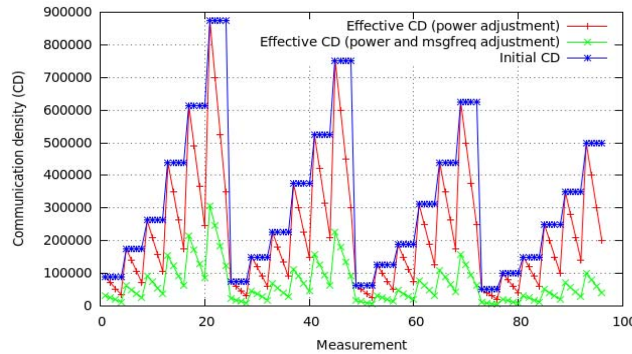


FIGURE V. – POWER AND MESSAGING FREQUENCY ADJUSTMENT EFFECT ON THE CD (THE CASE OF SAFETY MESSAGES)

ACKNOWLEDGMENT

This work is part of CooPerCom, an international research project (Canada-France). The authors would like to thank the Canadian National Science and Engineering Research Council (NSERC) and the French "Agence Nationale de la Recherche" (ANR) for their support to this project.

REFERENCES

[1] Maen M. Artimy, William Robertson, and William J. Phillips. 2005. Assignment of dynamic transmission range based on estimation of vehicle density. *2nd ACM international workshop on Vehicular ad hoc networks* (VANET '05).

[2] Caizzone, G.; Giacomazzi, P.; Musumeci, L.; Verticale, G.; , "A power control algorithm with high channel availability for vehicular ad hoc networks," *ICC 2005,* pp. 3171- 3176 Vol. 5, 16-20 May 2005

[3] Torrent-Moreno, M.; Mittag, J.; Santi, P.; Hartenstein, H.; , "Vehicle-to-Vehicle Communication: Fair Transmit Power Control for Safety-Critical Information," *IEEE Transactions on Vehicular Technology*, vol.58, no.7, pp.3684-3703, Sept. 2009.

[4] Huaying Xu and Matthew Barth. 2004. A transmission-interval and power-level modulation methodology for optimizing inter-vehicle communications. *1st ACM international workshop on Vehicular ad hoc networks* (VANET '04).

[5] Tamer ElBatt, Siddhartha K. Goel, Gavin Holland, Hariharan Krishnan, and Jayendra Parikh. 2006. Cooperative collision warning using dedicated short range wireless communications.*3rd international workshop on Vehicular ad hoc networks* (VANET '06)..

[6] Rezaei, S.; Sengupta, R.; Krishnan, H.; , "Reducing the Communication Required By DSRC-Based Vehicle Safety Systems," *Intelligent Transportation Systems Conference, 2007. ITSC 2007. IEEE* , vol., no., pp.361-366, Sept. 30 2007-Oct. 3 2007.

[7] Chonlatee Khorakhun, Holger Busche, Hermann Rohling. "Congestion Control for VANETs based on Power or Rate Adaptation". *5th International Workshop on Intelligent Transportation (WIT 2008)*, Hamburg, Germany, Mar. 2008..

[8] Marc Torrent-Moreno, Daniel Jiang, and Hannes Hartenstein. 2004. Broadcast reception rates and effects of priority access in 802.11-based vehicular ad-hoc networks. *1st ACM international workshop on Vehicular ad hoc networks* (VANET '04).

[9] O. Chakroun and S. Cherkaoui and J. Rezgui, MUDDS: Multi-Metric Unicast Data Dissemination Scheme for 802.11p VANETs, 8th International Wireless Communications and Mobile Computing Conference, IWCMC, 2012.

[10] D. Jiang and C. Qi and L. Delgrossi, Optimal data rate selection for vehicle safety communications, Proceedings of the fifth ACM international workshop on VehiculAr InterNETworking VANET 08 (2008).

[11] Robert E. Stanford. Reneging phenomena in single channel queues. Mathematics of Operations Research, Vol. 4, No. 2 :162-178, May, 1979.

[12] http://www.oregon.gov/ODOT/HWY/ACCESSMGT/docs/stopdist.pdf

[13] Hannes Hartenstein, K. Laberteaux, Inc Ebrary, VANET: vehicular applications and inter-networking technologies (2010)