Enhancing Safety Messages Dissemination Over 802.11p/DSRC

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***Abstract*— Direct radio-based vehicle-to-vehicle (V2V) communication can be used to prevent accidents and to provide accurate information on road state or surrounding vehicles intention. Both kinds of information can be used to enable drivers to react in time and avoid hazardous situations. While the IEEE 802.11p standard has specifically been adopted for vehicular communications, its Distributed Coordination Function (DCF) operation can cause poor delivery rates when the communication channel is congested or when messages need to be transmitted over distances higher than 300 meters. In this paper, we propose MORS, a technique for transmission power adjustment to avoid channel congestion, combined with an efficient multi-hop data dissemination scheme. The purpose is to ensure low delays and high delivery rates for V2V communications at distances higher than it would normally be possible with the same effectiveness with 802.11p alone. The power adjustment technique is fully distributed and asymmetrical, and the multi-hop data dissemination scheme is based on a newly designed multi-metric which characterizes the available links capacity. MORS determines, at each hop, the best available link choice to ensure both reliable transmissions and a minimum delivery delay while reducing congestion and network load though adaptive power adjustment. Simulation results confirm the effectiveness of the proposed transmit-power adaptation and multi-hop relaying schemes under various realistic traffic constraints.**

Index Terms—Vehicular ad hoc networks, safety messages dissemination, congestion control.

I. INTRODUCTION

Vehicular communication is of high importance to improve road safety by preventing hazardous situations and by providing information on the road state to make drivers aware of the surrounding environment. Vehicular Adhoc Networks (VANETs) leverage communicating devices to construct a global awareness of the surrounding environment and vehicles intentions. The first concern of using such networks is to extend the driver perception which is generally limited to line of sight. This, in turn, ensures high information reachability. In high speed environments such as highways and freeways, the reaction time must be reduced and consequently so must the information dissemination delay. The information dissemination delay is defined as the latency between the detection of a hazardous situation by a leading vehicle, the generation of an alerting message and its reception by pursuing vehicles. This leads to a highly priced constraint, i.e. a 100ms maximum dissemination delay constraint on emergency messages delivery specified for the IEEE 802.11p standard.

Network designers have to satisfy several constraints when designing protocols for vehicular networks; (1) ensuring reliable messages transmission with respect to the delay constraint especially in highly dense environments, (2) ensuring that a high broadcast load does not affect the network performances especially close to channel saturation threshold, and (3) ensuring the 1000 meters dissemination distance barrier specified by the standard.

While keeping these constraints in mind, it is clear that two major issues arise for VANETs; one related to the broadcast nature of these networks causing broadcasting storms, and the other related to their high speed topology changes causing network disconnection problems. A broadcasting storm is the result of multiple collisions caused by a multitude of broadcasting nodes at the same time, thus causing network performances rapid degradation. Using high data rates reduces the overall dissemination delay but makes the broadcasting storm phenomenon happen earlier and faster. Broadcasting storms have, of course, the most harmful effects when the network is close to its capacity saturation. The network disconnection problem happens when no relaying node is available to forward messages from a particular section of the road to another. This kind of dissemination chain breakage is related to vehicles velocities and their unpredictable displacements. It can cause the non-delivery of a safety related message which makes the technology useless.

The work presented here complements the approaches in [10, 11] and proposes an efficient, overhead-free approach for congestion control and multi-hop data dissemination in VANETS. The proposed scheme, called MORS, leverages locally measured metrics and by the way reduces the amount of control messages exchanged. Its dissemination metric is based on an approximation of the expected reliability and communication range usage. This novel approach aims to improve the packet reception rate and reduce the end-to-end message dissemination delay. It treats mainly the case of emergency messages dissemination in a multi-hop manner applied in combination with a highly efficient time-synchronized channel access scheme, i.e. VDA [10]. It is based on multiple optimization-under-constraint processes that characterizes; 1) the communication range choice and 2) the optimal relay designation taking into account the actual network configuration.

The remainder of this paper is composed of sections as follow; the second section presents the VANET related challenges and related works. Section III introduces our approach while decorticating its motivations and operating phases. Section IV presents the results of extensive simulations and discusses them. Finally, section V presents the concluding remarks to the paper.

II. 802.11P MAIN CHALLENGES AND RELATED DESIGN APPROACHES

The 802.11p standard specifies two types of safety messages; (a) periodic and (b) event triggered. Periodic messages contain status information from surrounding vehicles and potentially aggregated information from multi-hop neighborhood. Based on reports and studies, multiple messages per second are needed to provide the envisioned accuracy for safety applications. The key challenges related to such beaconing activity are how to ensure the fair trade-off between data availability and freshness without causing channel congestion. In previous work [10], we introduced Vehicular Deterministic Access (VDA), a newly designed time-synchronized access scheme for vehicular network. This scheme shows a better behavior in dense environment. In this previous work, we denoted that while enhancing transmission power extends the communication range, it causes interferences in the close vicinity of the emitting vehicle which leads to a drop on the packet delivery reliability. Also, a highly important feature in VANETs that have to be specified is considering security-related overhead, beacons will have a large size up to 800 bytes [11]. This will result on a more severe congestion as the payload is disseminated on multiple messages.

Considering these challenges and taking into account that while VDA constitutes a better access technique and ensures time synchronization between vehicles, it only operates in the two-hop vicinity and do not provide any congestion control mechanism. It is worth noting that the maximum achievable range with acceptable reliability on one hop does not exceed 300 meters and to account for the 1000 meters dissemination barrier, messages have to be forwarded for multiples hops. Since there is no central coordinating entity, such system has to be fully distributed while ensuring information provisioning on all the surrounding vehicles.

Multiple schemes have been introduced in the literature to overcome the messages delivery issues while respecting bearable delays. In this subsection, such solutions will be discussed with respect to their design and can be roughly presented in two categories; (1) Uni-metric and (2) Multi-metric designs.

A. Uni-metric schemes

Smart Broadcast (SB) and Position-Based Adaptive Broadcast (PAB) [3] in the other hand integrates a safe design, store-and-forward, trying to use efficiently the network resources but does not guarantee delivery delays. They use distance, position and speed information. Korkmaz et al. proposed two designs; Urban Multi-hop Broadcast (UMB) [2] which uses a continuous messages exchange to calculate distances between communicating nodes and elects the farthest one as a relay. Ad hoc Multi-hop Broadcast (AMB) constitutes an improvement to UMB which elects the closest node to an intersection as a relay to that particular section of the road. Fast Broadcast (FB) [4] uses greedy forwarding and adapts the waiting time before rebroadcasting by giving the farthest vehicle in the communication range higher priority to relay the message. Reliable and Efficient Alarm Message Routing in VANETs (REAR) [5] considers the Packet reception rate (PRR) as a main metric and can offer guarantees on messages delivery but does not offer any bound on data forwarding delays. ROMSGP [12] and GVGrid [12] respectively rely on categorizing communicating vehicles based on their speed, heading, and the number of sub-sequent links disconnection. Designs leveraging control messages exchange will induce an overhead which can have negative impact on the network performance. Reducing hop count guarantees lower End-to-End (E2E) delivery delay. Using PRR as a metric means giving all nodes capabilities to compute it introduces higher processing time in nodes which in term causes higher delay. Designing a dissemination scheme around one metric is generally insufficient and more complex approaches have been proposed. The next section will focus on multi-metric designs.

B. Multi-metric schemes

Naumov et al. introduced Connectivity Aware Routing (CAR) [9] which by pre-establishing the dissemination path guarantees lower delays. It uses HELLO messages exchange from the source to the destination and on the reverse path to construct a routing route similarly to AODV. DV-CAST [6] ensures high messages delivery by electing the less loaded links all over the routing path to construct a route. Moreno et al. in [8] proposed a highly dynamic transmission power adaptation scheme which guarantees a fair channel access between vehicles. It involves exchanging control messages containing status information such as network density and neighbors' number. MHVB introduced by Tatsuaki et al. [7] tunes the beacons messaging frequency depending on the number of communication nodes in the communication range to avoid network congestion. It does not offer any guarantee neither on the rate of successfully delivered messages nor on the delivery delays. Multi-metric techniques introduced more awareness of the network state and tried to palliate to the shortcomings of the Uni-metric ones. However, they often rely on a continuous exchange of messages that introduces an overhead and weighs on the network performance.

Here after, a more complex approach will be discussed based on two distinct sub-models; (1) a power adjustment technique based on an optimization process to select the right emitting power with respect to the induced communication density (CD) and (2) a fully distributed data dissemination scheme based on local measurements and on a newly designed multi-metric that takes into account; (a) distance between emitting and receiving nodes, (b) the link reliability in term of expected PRR.

III. PROPOSED APPROACH: MORS

Multi-metric routing protocols have so far been proposed and as discussed earlier are mainly based on a continuous exchange of information to achieve a global awareness of the network state. Two main approaches were introduced to reduce the overhead caused by this continuous exchange; controlling the emitted power or adjusting the control messages broadcasting frequency. In this work, we present our proposed scheme, called Multi-metric Overhead-Free Routing Scheme (MORS). MORS is a multi-metric data dissemination scheme based on two primary metrics; (a) PRR; and (b) Distance (D) over communication range (CR) ratio ($^{D}/_{CR}$).

MORS operates in two phases and is the combination of two schemes that are time-dependent one of the other; (1) Fully Distributed Congestion Control (FD2C) which performs a range/power adaptation to guarantee the maximum achievable PRR according to the network state in term of congestion and communication density (CD), (2) Unicast Multi-hop Data Dissemination (UM2D) which main function is to perform the next-hop relay node election based on a compromise between envisioned PRR while maximizing the range usage. The use of PRR guarantees reliability on messages forwarding and the distance over range ratio maximization forwarder-based choice guarantees less hop and reduces the overall dissemination delay.

In this paper, we assume that all vehicles are equipped with 802.11p enabled communication devices which are DSRC/802.11p standard compliant. All of them use VDA as a channel access scheme [10] and all are capable of switching to another emitting power level in 2 ms maximum latency. We assume also that when a node is transmitting a message, the power level used for such transmission is tagged on a special field in the message. Communication density (CD) in this paper refers to the definition made by Jiang as specified in eq.1 [1], a combination of the transmission range (meter), the messaging frequency (Hz) and the vehicles density (vehicle / km road).

$$CD = Msg\_freq.Trans\_range.Veh\_density \qquad (1)$$

To present our proposed adaptation and multi-hop overhead free relaying scheme, we sequentially present each phase depending on the execution time compared to global time for all the scheme aspects to operate. This segmentation will be presented on two sub-sections; (a) the adaptation phase and (b) the dissemination phase.

A. *Fully Distributed Congestion Control (FD2C)*

In this section, we present the first optimization sub-process, a fully distributed congestion control mechanism based on CD real-time measurements. It controls the load by operating a transmitting power adjustment locally made in each node. Each node estimates the generated communication density. Each node estimates the generated load by performing an evaluation of the CD based on the equation 1. This evaluation is performed using overhearing technique. Using this technique, a node can detect vehicles in its communication range and by the way can evaluate the overall locally generated CD. Note that the range estimation is based on the used propagation model, designated here by the function ***Propag***. For each node $n_i \in N$, $CR(n_i) \in (0,1]$, the communication range assigned will be a percentage of the maximum achievable transmission range using the maximum emitting power. Using the conclusions made by Jiang et al. [1] that for a fixed CD, the network behavior and performances are the same. The process can be modeled by an optimization under constraint problem as illustrated below, where Pwr_i represent the node i actual transmission power, CD and CD_{th} point to the measured CD and the CD threshold respectively. Note that Pwr_i constitutes discrete power value selected by the node depending on the equipment capabilities and the envisioned granularity.

$$\max_{CD \leq CD_{th}} \{CR_i = \text{Propag}\ (Pwr_i)\} \qquad \text{(P2.1)}$$

The optimization process is promoted involving maximizing the transmission range to keep a low delay while ensuring reliability over a certain threshold. It's worth noticing that, since an overhearing technique is introduced, this approach can be easily extended to support multiple messaging frequencies and message sizes.

B. *Unicast Multi-hop Data Dissemination (UM2D)*

Early provided conclusions concerning metric-based forwarding decision provides an overview of the alternatives that can be taken to produce an efficient forwarding scheme. The need of the multi-hop data forwarding is persistent as we face the challenging dissemination problem over relatively long distances. It is clear that uni-metric based dissemination solutions are insufficient and a combination of those metrics is needed. Based on these conclusions, we present a newly designed multi-metric based on real-time measurements using as expected, the two major qualities in VANETs dissemination schemes, i.e. delay and reliability. This multi-metric is a combination of the distance evaluation to ensure the highest distance propagation and the reliability maintain expressed by the link quality in term of expected probability of reception. Taking these remarks into account, we checked the validity of the possible usage of such metrics and recap them in Table I.

TABLE I –METRICS CHOICE AND VALIDATION

		Routing metrics				
		Distance	Comm. density	Geograph area	Throughput	Link state
Perf. metrics	Throughput		X			X
	Delay	X	X	X	X	X
	PRR	X	X		X	X
	Estab. delay	X	X	X	X	X
	Awareness	X	X			X

As FD2C uses the communication density to perform an adaptive congestion control of the network load, we took the initiative to design our multi-metric around the two other primary routing metrics that have the most significant impact on the measured performance metrics, i.e. distance and link state. The distance choice will ensure messages delivery to the farthest node. Since the channel access delay constitutes the most significant portion of the delivery delay, the choice of the farthest node reduces the expected hop count and consequently the overall dissemination delay. This approach is combined with an implicit acknowledgment; each node that hears that its last emitted packet is forwarded will consider it as a successful receipt. Note that each message contains an extra field corresponding to the emitting power, Pt, which is used to feed the distance evaluation in the receiver side and the address of each chosen relay will be tagged on the message so it can be aware to act as a relay node. Link state can be characterized using multiple manners; life duration, number of disconnections, and duration of disconnections. The link state choice in term of estimated PRR, by contrast will ensure the reliability of the link choice. We took a simplified form of the PRR estimation over distance as illustrated in equation 2 [14] where the PRR is function of the maximum achievable communication range and the distance between an emitting node and a receiver (the actual relay).

$$Prr(A) = e^{-3(A)^2}\left(1 + 3(A)^2 + \frac{9}{2}(A)^4\right) \quad (2)$$

Where A is expressed as

$$A = \begin{cases} \frac{Dist_i}{CR}, & dist_i < dist_{cross} \\ \frac{{Dist_i}^2}{CR}, & dist_i \geq dist_{cross} \end{cases}$$

The final objective function U can be written as a combination between the PRR estimation, the ratio between the link length and the maximum achievable range, and β, 0≤β≤1as a proportionality function between the two main metrics so we can further one over the other depending on the targeted safety application. The objective function can be written as follow where $Dist_i$, $Dist_i \leq$ CR designates the actual distance between an emitting node and a possible relay in the communication range (resultant of P2.1), $Prr(dist_i, CR)$ designate the estimated link PRR.

$$U(\beta, Dist_i, CR) = \beta\left(\frac{Dist_i}{CR}\right) + (1-\beta)Prr(A) \quad (3)$$

$$A = \begin{cases} \frac{Dist_i}{CR}, & dist_i < dist_{cross} \\ \frac{{Dist_i}^2}{CR}, & dist_i \geq dist_{cross} \end{cases}$$

The constraint expressed on the distance ensures that none of the nodes that are out of the communication range already assigned by FD2C is selected as a relay. This maximization process is performed on every hop for each available link l_i and eventually can be extended to multi-hop if a higher detection range DR_i is allowed. The resulting optimization sub-process in which we try to maximize the objective function U is as follow.

$$\max_{\substack{0 < Dist_i/CR \leq 1 \\ 0 < Prr(Dist_i, CR) \leq 1 \\ 0 \leq \beta \leq 1}} \{U(\beta, Dist_i, CR) = \beta(Dist_i/CR) + (1-\beta)Prr(A)\} \quad (P2.2)$$

$$A = \begin{cases} \frac{Dist_i}{CR}, & dist_i < dist_{cross} \\ \frac{{Dist_i}^2}{CR}, & dist_i \geq dist_{cross} \end{cases}$$

Then, the whole optimization process combination can be rewritten as an algorithm combining the two main sub-processes P2.1 and P2.2 while keeping in mind the temporal link governing their execution and the use of the dynamic programming approach on hop-by-hop basis. Note that the envisioned optimality is only local to prevent network congestion caused by information gathering to construct global network knowledge.

Algorithm 2.1 Power adjustment (FD2C)

1: CD_{th}: *CD threshold*
2: CD_t: *CD measurement at instant t at the node side*
3: CR_i: *maximum transmission range for node i*
4: Pwr_i: *emitting power at node i*
5: ***For** each node i*
6: ***If** ($CD_t < CD_{th}$)*
7: $Pwr_i = Raise\_pwr()$
8: ***Else if** ($CD_t > CD_{th}$)*
9: $Pwr_i = Reduce\_pwr()$
10: ***Else***
11: $Pwr_i = Maintain\_pwr()$
12: ***End if***
13: ***Return** Pwr_i^*, CR_i^**
14: ***End for***

Algorithm 2.2 Relay selection (UM2D)

1: *Given (CR_i^*, β)*
2: *j: relay ID, k: table index*
3: $Dist_j$: *distance from node j*
4: *β: proportionality function*
5: *Table: connectivity table at node i side*
6: U_{ij}: *objective function as in eq.6*
7: ***For** each possible relay j in CR_i^**
8: U_{ij} *= evaluate_U(β, $Dist_j$, CR_i^*)*
9: *Table[k]= add_entry(k, j, U_{ij})*
10: ***End for***
11: ***Return** j^*=Table[index_of(Max{U_{ij}}),1]*

The table (Table II) below shows an example of the locally generated connectivity table made in the node A side while varying β parameter. The highlighted cells point to the optimal relay choice and gives measurements of the expected PRR.

TABLE II –EXAMPLE OF LOCAL CONNECTIVITY TABLE (NODE A, $CR_i^* = 100$ METERS)

Link	a,b	a,c	a,d	a,e	a,f
Link length(meters)	50	70	60	30	100
PRR evaluation	0.95	0.81	0.9	0.98	0.42
U=fct(β=0.5, $Dist_j$, CR_i^*)	0.72	0.75	0.73	0.65	0.71
U=fct(β=0.3, $Dist_j$, CR_i^*)	0.82	0.78	0.81	0.79	0.6
U=fct(β=0.7, $Dist_j$, CR_i^*)	0.63	0.73	0.69	0.50	0.82

IV. System design analysis and tests results

A. *Algorithms complexity check*

The fact of dissociating the whole problem into two main sub-problems, while maintaining their temporal dependency, reduces the overall problem complexity in terms of execution and reduces its resolution latency. Let assume the existence of *n* nodes in the network and consider that simple instructions as comparisons does not induces more complexity, P2.1 will run *n* time one for each node, which constitutes a complexity up to O(n). Assume that $m \in n$ nodes are in the communication range of the node *i* with $m < n$ which gives to P2.2 a complexity up to *O(m)* with *O(m)<O(n)*. Thus, the overall approach complexity can be expressed as $O(n+m)$.

Let assume the case where we are using the problem definition denoted P1; for each node *i* and for each power levelPwr_i, the whole P2.2 algorithm will be executed. Thus, the overall problem complexity will be $O(n.m)$.

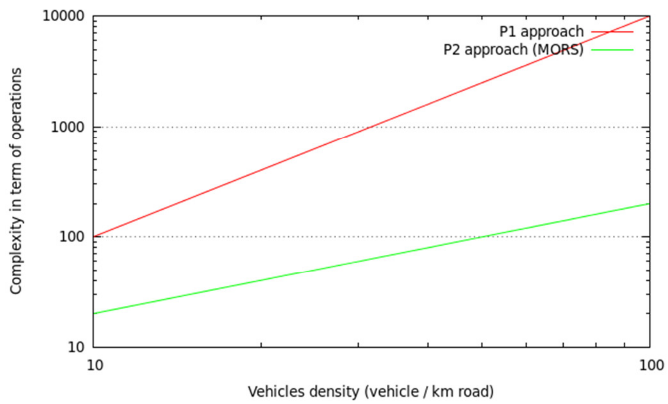

Figure I. – P1 and P2 algorithm complexity check

B. *Simulations results*

In this section, NS-2 simulations results were conducted and their results will be discussed compared to basic Vehicular Deterministic Access (VDA) and Distributed Coordination Function (DCF) to prove the scheme effectiveness and its shortcomings. We implemented MORS over Nakagami-m fading channel and compared its effectiveness while varying proportionalities in the two main metrics considered and in different communication densities. Two main metrics are evaluated; (1) the packet forwarding delay and (2) the packet reception rate considering; (a) one hop relaying scheme and (b) its extension to multi-hop. As MORS integrates an adaptation scheme and a novel approach on how to disseminate messages using new metrics, the price of such adaptation has to be discussed.

1) *Simulation parameters:*

The simulated environment is an 8 lane highway (4 in each direction) containing each 10 vehicles while varying their inter-distance to simulate density variation and while varying their communication range and velocity. The messaging frequencies reflect the coexistence of safety related and beacon messages in the same communication area. We implemented FD2C and UM2D over standard VDA discussed in [10]. Simulations parameters are summarized in Table III. Tests are presented based on two main sub-sections; (1) using equal proportionality between the two main metrics and (2) varying such proportionality to identify its impact on the global network behavior. In this section, MORS mean FD2C and UM2D implementation over VDA access scheme , VDA and DCF mean respectively VDA access and DCF access schemes applied to two-hop neighborhood. The newly designed metric was implemented as a fully new routing scheme based on a hop-by-hop routing and multiple flows were simulated in each scenario. Each of which contains two types of priorities; (a) highly prioritized traffic that mimic emergency messages (S) and (b) low prioritized traffic for routine messages on a periodic messaging basis (B). The presented results only consider mean delay and PRR values for emergency messages as they are the essence of this paper.

Table III – Global simulation parameters

Parameter	**Value**
Messaging Frequency	10-25 per second (S+B)
Vehicle densities	10-100 veh/km/lane
Vehicle velocity	60, 80, 100, 120 km/h
Simulation duration	60 seconds
Transmission rate	6 Mb/s
Transmission power	6 levels ⇔ 50-300(meter)
Radio reception threshold	-90 dBm
Signal propagation model	Nakagami-m (m=3)

2) *Packet reception rate analysis:*

The first step in validating the proposed model and approach is to compare their effectiveness on a one-hop basis and extend it to a multi-hop approach. Hereafter, results will be presented based on such a division.

Figure II shows the impact of varying vehicles inter-distance over communication range on the PRR while taking into account transmission ranges up to 300 meters. As expected, using the Nakagami-m model extends the messages reachability to distances over those when using the TwoRayGround model but has a more realistic impact on the PRR all over distances [13]. Multiple β values were simulated and the system behavior in term of PRR was compared to theoretical Nakagami-m model to significant points where the selected vehicle meets the optimal distance choice using such β values. Conclusions can be made that for low transmission ranges (corresponding to low power usage), the measured PRR meets the Nakagami-m theoretical ones. For high power usage, the PRR measured only meets the theoretical one on distances up to approximately 70% of the maximum achievable range. This is due to, the probability of collisions that raises especially those caused by the hidden node problem. Such a problem is persistent on vehicular networks since neither RTS/CTS nor ACK usage is allowed.

Figure III. (A) shows the packet reception rate on a multi-hop dissemination up to 1km in various communication densities for MORS, VDA, DCF, and two chosen geocast dissemination schemes, i.e. DTSG and ROVER. VDA and MORS outperform DCF as they enhance scheduling by allocating TS to communicating vehicles. MORS integrates an extra-enhancement since it introduces a power adjustment and a new parametric relay election technique.

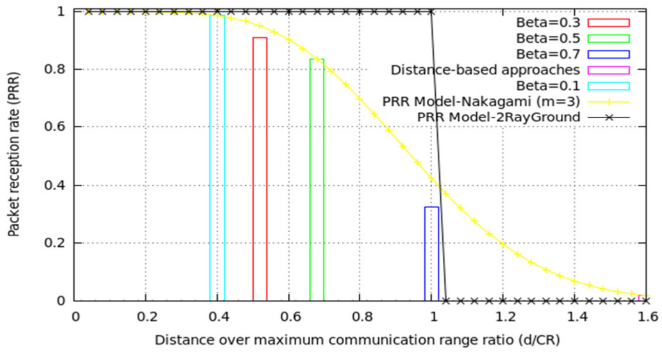

FIGURE II – PACKET RECEPTION RATE CORRESPONDING TO THE OPTIMAL RELAY SELECTION FUNCTION OF DISTANCE OVER COMMUNICATION RANGE RATIO.

At low communication densities, MORS outperforms VDA only by 10% and reaches a PRR up to 97%, while in medium and high communication densities; the performances gap is wider which proves the power adjustment and relay election combination effectiveness over standard VDA. This is due to MORS capability to avoid congestion, adapt the communication density and therefore avoid possible packets losses. DTSG [16] introduces another approach on geo-casting, called time-stable as it acts on the time when messages are geo-casted. In the other hand, ROVER [15] is a simplest geo-casting technique based on zones definitions (Z. of forwarding and Z. of relevance). It integrates neighbor's discovery technique based on ZZREQ/ZZRSP messages exchange for ZOR and groups' definition, which at the end lead to extra overhead which can loosen the network performances. In addition to the latter, a lost ZZREQ/ZZRSP in this design means that a part of the multi-cast tree will not be aware of the event. This is highly probable especially in medium and low density networks. We notice that ROVER presents a reverse behavior compared to other schemes. It performs better in high load conditions and reaches a reception probability up to 80 %. On the other hand, DTSG is only ensuring 60% reliability and only at close range under 150 meters. This supports the remark that MORS is particularly efficient in medium and high communication densities and does not induce and extra-overhead thanks to its locally measured metrics.

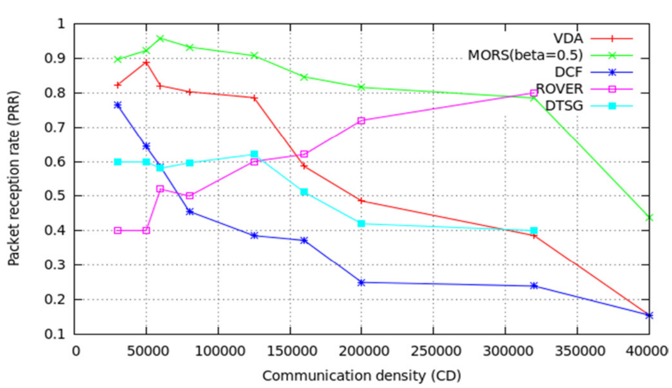

FIGURE III.(A) – PACKET RECEPTION RATE IN DIFFERENT CD CONDITION.

Figure III. (B) shows the impact of varying β values on MORS performances on a multi-hop dissemination basis. The use of lower β values makes MORS behave more efficiently in term of PRR. This is due to the choice of closest nodes as relay, while the use of higher β values makes the reverse effect by reducing the PRR since it elects the longest links to forward emergency messages. But, in the other hand reduces the overall dissemination delay since it reduces the hop count. Due to these links instability, the resultant PRR is lower than in the case when using high β values.

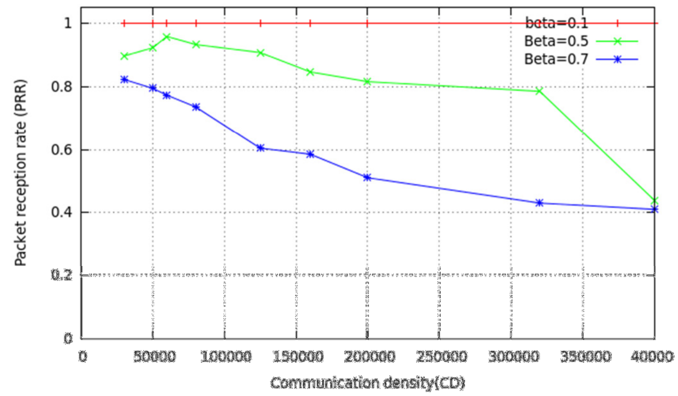

FIGURE III.(B) – PACKET RECEPTION RATE (MORS) VARYING Β VALUES SUBJECTED TO DIFFERENT CD CONDITIONS.

3) *End to End delay analysis*

MORS performance in term of end-to-end delay was studied and compared to VDA and DCF while varying β values, subjected to various communication densities. Figure IV.(A) shows that, since MORS integrates a power adjustment scheme, it can overcome the disconnection problem that can happen in low load conditions. MORS can perform data dissemination in densities less than 25K CD (which correspond to vehicles density down to 10 vehicles per Km road) even if the latency is greater than expected. The extra delay is caused by the power adjustment latency, since the power will be increased gradually until the system finds at least one viable relay. In stable condition, VDA overcome MORS performances, this is due to the relay selection latency while VDA uses a simplest greedy forwarding technique based on the farthest node election. Note that VDA operates only up to two-hop, however, MORS operates in a multi-hop manner up to 1 km distances (at least four hops, using the highest power). In medium and high loaded conditions, MORS outperforms VDA due to its capability to prevent congestion by reducing the number of collisions and electing the best available links for messages delivery. DCF is outperformed by VDA and MORS in both high and low load condition and presents respectively about 46 % and 48 % excess E2E delay.

MORS clearly overcome the two geo-casting technique since it deliver the message to the destination in 1/10th of the time and without introducing overhead which is by the way necessary for ROVER functionalities since it serves to collect information on neighboring vehicles and on defining the ZOR and ZOF.

In fact, ROVER does not seems to be useful for VANETs since it takes over 300ms for an end-to-end delivery which is three time more than the standard specification for safety messages. DTSG introduced the idea of helping vehicles navigating in the opposite direction and which are used to ensure messages delivery in pre-stable period. Geo-casting needs a continuous exchange of control messages containing information such as positioning, cluster formation, speed, and heading. In addition to the misused network resources, generally geo-casting techniques need spatial relevance but do not ensure any constraint on delivery delay.

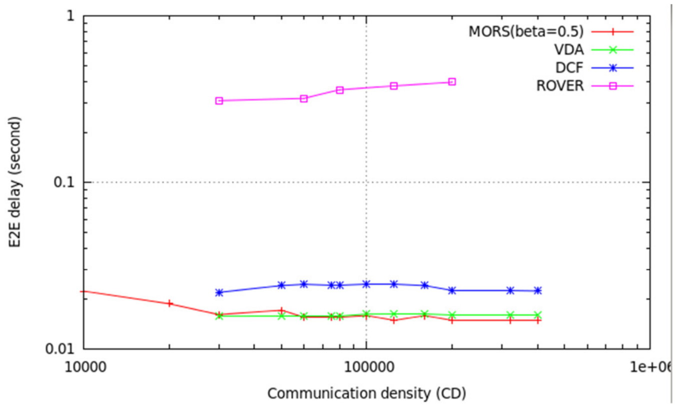

FIGURE IV.(A) – END-TO-END MORS MEAN DELAY WHILE VARYING CD BY VARYING COMMUNICATION RANGE, VEHICLES DENSITY AND MESSAGING FREQUENCY.

Figure IV.(B) shows the impact of varying β values on the E2E delay. When using high β values such as 0.7, the distance is sub-served over reliability. Is such a case, the dissemination delay will be reduced but links will be subjected to get broken or to multiple fluctuation that can cause packets losses. In the other hand, using lower β values, reduces the probability of packets collisions or links break since it carry favor to the reliability, but raises the E2E delay since the system needs numerous hops to attend the 1Km dissemination barrier. In low densities, the adaptation scheme induced an extra-delay for all β values and its impact is inversely proportional to β. While, in medium densities, the system behavior is relatively stable, in high densities, the delay increases especially for extreme β values. This is due to the need of adjustment to overcome the network congestion.

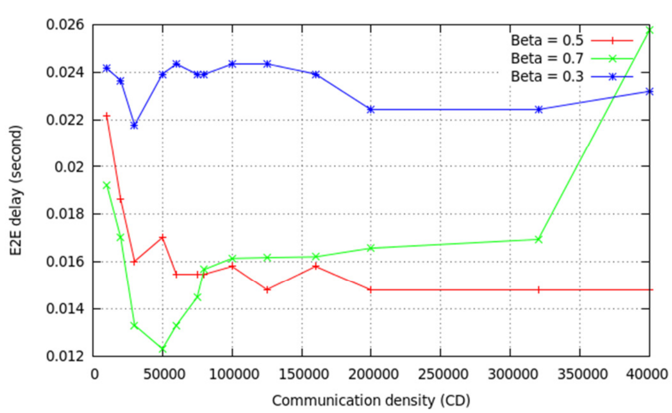

FIGURE IV.(B) – END-TO-END MORS MEAN DELAY VARYING BETA PROPORTIONALITY PARAMETER AND SUBJECTED TO DIFFERENT CD.

4) *Delay-PRR tradeoff metric*

As MORS introduced a tradeoff between the distance over communication range and the PRR, we define a new metric to measure its performances and compare them to other approaches such distance-based forwarding and using other access schemes. Let us define PDR as the PRR over Delay ratio which characterizes the forwarding scheme effectiveness function of the two main performance metrics in VANETs.

$$\mathrm{PDR} = \frac{\mathrm{PRR}}{\mathrm{Delay}}$$

To maximize such a metric, a scheme has to reduce the dissemination delay or increase the PRR. An optimal solution tries to reach the two goals simultaneously but such a goal is non-realizable since the two entities are dependent one on the other. Reducing the delay means forwarding to longer distance and that latter affects the PRR since longer links are less reliable and subjected to signal fluctuations. The figure hereafter presents the resulting PDR metric measurement for most significant β values in MORS compared to distance-based approaches whether using VDA or DCF access schemes. Note that distance-based approach means a broadcast dissemination techniques based on greedy forwarding up to 1 Km.

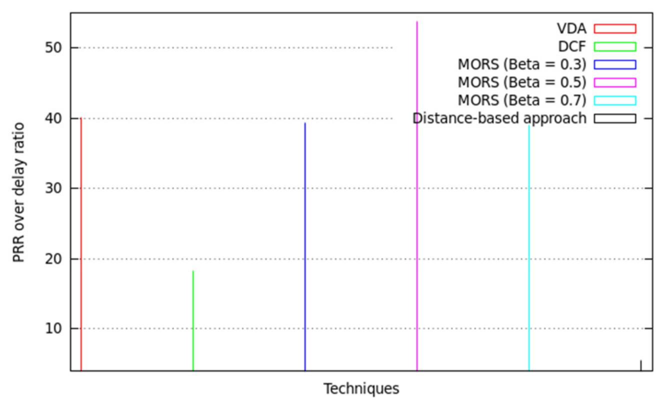

FIGURE V. – RESULTING PDR METRIC COMPARISON

The best performance is ensured when taking into account β value equal to 0.5 thus means taking into account PRR and distance equally proportional. Both β values equal to 0.3 and 0.7 ensure the same behavior and a reduced gain of approximately 20 % compared to equally-proportional metrics choice, which is almost the same compared to VDA performances. DCF and Distance-based approaches present the least efficient approaches since they slattern the network performances and only consider distance rather than both metrics which at the end reduces considerably the PRR that can be guaranteed.

Tests were conducted to figure out the percentage of time that *UM2D* selects the best relay compared to theoretical analysis. We tested every scenario over 10 times in which over 500 messages are exchanged and multiple relay over the dissemination path are elected and compared the results to the theoretically deduced ones. We noticed that, in light communication densities, the relay selection scheme behaves greatly and elects the best relay 83% of the time. In contrast, in medium and high communication densities, it efficiency drops to 60 % of the time. This is due to decreasing reception probability over long distances. As MORS elect the farthest relay in the communication range, signals can fluctuate at high communication range and distort the distance and PRR estimation resulting in a sub-optimal relay election.

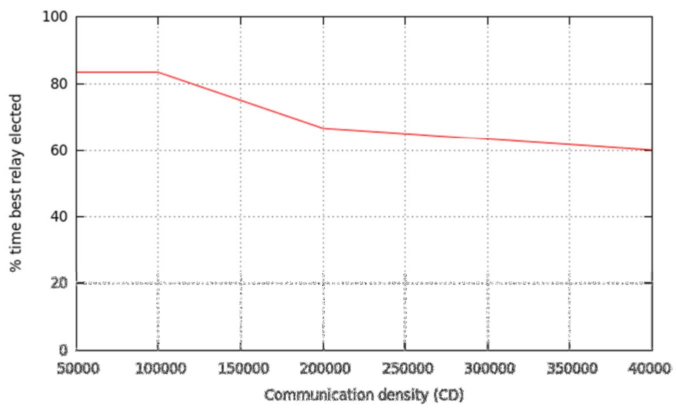

FIGURE VI.(A) – TIME PERCENTAGE OF ELECTING THE BEST RELAY

5) Adjustment impact on delay and communication density

As MORS introduced an adaptive behavior, its impact on the network performances has to be measured. In MORS, a power adjustment phase (FD2C) precedes the relay election for the messages dissemination (UM2D). Such power adjustment phase induces an extra-delay which is plotted in Figure VI.(B) as the power adjustment latency. Note that the presented delay represents a mean delay for multi-hop relaying up to 1 Km distance and that the power-hop latency specified by the supported equipment in the simulation is 2 ms. Even with that additional delay, MORS outperforms DCF in all densities environments and VDA in medium and high communication densities conditions which proves its main design goals; efficiently disseminate messages in high communication density environment .

Figure VI.(C) shows the effect of the adaptation scheme on the measured CD. We remarks that the communication density gain raises when the high communication range and frequencies are used which confirms MORS effectiveness in high and medium densities.

V. CONCLUSIONS AND FUTURE WORK

Through this paper, we introduced a fully adaptive distributed messages dissemination design for vehicular networks. This particular design uses locally collected information and does not need control messages exchange to operate and consequently does not introduce an overhead to the network. Using simulation, we demonstrated MORS effectiveness compared to standard VDA and DCF in terms of E2E and PRR. MORS is highly suitable for medium to high communication environments. It proved to be effective for highly congested environments where packets collision causes network performances to degrade rapidly. The added proportionality between the two main metric constitutes another adaptive mechanism that can be used to handle differently various type of emergency messages and by the way enhance the global scheme performances and adaptability.

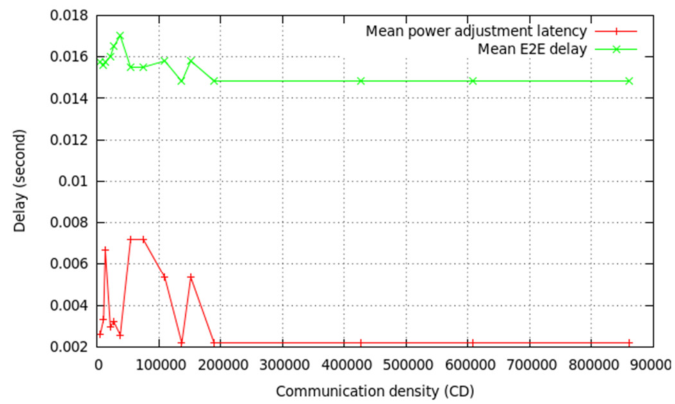

FIGURE VI.(B) – MORS POWER ADJUSTMENT LATENCY AND E2E DELAY

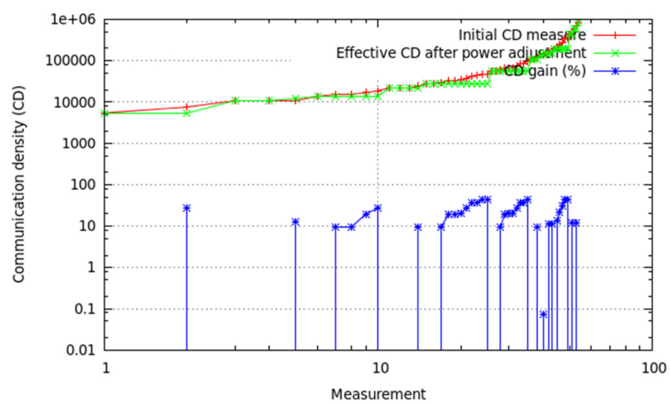

FIGURE VI.(C) – POWER ADJUSTMENT EFFECT ON THE CD

VI. ACKNOWLEDGMENT

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