MUDDS: Multi-Metric Unicast Data Dissemination Scheme for 802.11p VANETs

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***Abstract*—Vehicular ad hoc networks (VANETs) leverage communication equipment and infrastructures to improve road safety. These networks, by the rapid change of their topology, can experience mainly two major problems; (1) the broadcasting storm and (2) the network disconnection due respectively to high vehicles density and their velocity. In this paper, we propose a new unicast data dissemination scheme based on distances estimation using Received Signal Strength (RSS) measurements and congestion detection by mean of a newly designed metric; called Multi-metric Unicast Data Dissemination Scheme (MUDDS). MUDDS adapts the transmission range so that congestion can be avoided. It performs the best available link choice to guarantee both reliable transmission and minimum delivery delay. MUDDS focuses on the broadcasting storm and the network disconnection problems simultaneously. Simulation results confirm the effectiveness of the proposed on-demand adaptation and relaying scheme and its impact on network performance under various traffic constraints.**

***Index Terms*—Vehicular ad hoc networks, multi-metric, broadcasting storm, network disconnection, congestion avoidance.**

I. Introduction

Vehicular communication is an upcoming and prodigious concept relying on communication infrastructure and equipment to reduce accident and to save lives. VANETs leverage wireless communications technologies and techniques so that vehicles can be aware of their surrounding environment. The major challenges in vehicular networks are: (1) how to design a system or a scheme that can satisfy the applications constraints and can allow the drivers reacting in time? (2) how to ensure that the information is delivered with respect to transmission delay constraint?

Two classes of messages can be distinguished in VANETs; safety and private messages. There are two types of safety messages; emergency messages and routine messages. Emergency messages are critical, event driven and delay sensitive. Routine messages are periodically broadcasted and support information on weather, road state, etc. Private messages are related to functionalities such as navigation and entertainment. They are throughput sensitive and follow an on demand scheme.

The broadcasting storm is a phenomenon that happens when multiple communicating vehicles are broadcasting messages at the same time. Due to multiple collisions that can happen, network performances degrade rapidly. This phenomenon has a deeper impact when the network is closer to its capacity saturation.

The network disconnection problem happens when the only available link to forward data from a particular section of the road to another became unavailable. This phenomenon is highly related to vehicles velocities and to the pseudo-unpredictable character of their displacements.

This work complements the approach in [15] and proposes an efficient, overhead-free approach for congestion control and data dissemination in VANETs. MUDDS uses local measurements and does not need a continuous exchange of information. It does not induce an overhead and integrates a novel dissemination metric called LA, based on the link availability rate and distances measurements. This novel approach aims to improve the efficiency of messages dissemination by improving Packets Reception Rate (PRR) and reducing the End-to-End (E2E) message dissemination delay.

The remainder of this paper is organized as follow; section II discusses some proposed schemes for data dissemination considering their design metrics. Section III introduces our proposed scheme, MUDDS, and its different operating phases. Section IV presents the proof of our concept and gives an overview of the expected results. Finally, section V concludes the paper.

II. Related works

Intelligent transportation systems (ITS) denote the use of the new information and communication technologies to improve transportation. This work addresses some issues encountered with such systems, particularly, the broadcasting storm and the network disconnection problems. Some schemes have been proposed in the literature whose main goal is to ensure messages delivery with the best achievable Quality of Service (QoS) [10], [11], [12] based on link state [13], [14] or disconnections number [9], [17], [18]. In this section, solutions will be discussed with respect to their design and especially their dissemination metrics. These solutions can be roughly divided in two categories; (1) Uni-metric and (2) Multi-metric solutions.

A. Uni-metric schemes

Korkmaz et al. proposed Urban Multi-hop Broadcast (UMB) [2]. UMB uses the distance between communicating nodes to elect the farthest node as a relay. Ad hoc Multi-hop Broadcast (AMB) is an improvement of UMB where the closest node to an intersection is selected as a relay to that section of the road. Fast Broadcast (FB) [4] uses the same principle as

UMB. It operates in two phases; a range adaptation phase and a dissemination phase in which the distance based forwarding scheme is applied. Smart Broadcast (SB) and Position-Based Adaptive Broadcast (PAB) [3] implement a store-and-forward scheme trying to use efficiently the network resources. SB and PAB rely on distance, position and speed information. Reliable and Efficient Alarm Message Routing in VANETs (REAR) [5] considers as performance metric the PRR. The PRR gives an information on how efficient is the dissemination scheme and how reliable is the data forwarding. REAR guarantees messages sending reliability but does not offer any bound on data forwarding delay. Receive On Most Stable Group-Path (ROMSGP) [17] and GVGrid [18] respectively rely on categorizing communicating vehicles based on their speed and heading, and on the number of sub-sequent links disconnection. Limiting the number of hop reduces the overall delay and guarantees a lower delay. The use of the PRR as a metric, assumes that every node has capabilities to compute this metric and introduces processing time in nodes. The use of only one metric for data dissemination decisions is generally insufficient and schemes with multi-metric approaches have been proposed in the literature.

B. Multi-metric schemes

DV-CAST [6] uses density and connectivity information to perform message relaying. It ensures a high messages forwarding reliability by choosing the less loaded links all over the routing path. Tatsuaki et al. proposed Multi-Hop Vehicular Broadcast (MHVB) [7]. This solution tried to avoid network congestion by tuning up the messaging frequency depending on the network state. MHVB does not offer any guarantee neither on the rate of successfully delivered messages nor on the delivery delays. Moreno et al. in [8] proposed a dynamic transmission power adaptation scheme to guarantee a fair sharing of the network resources between vehicles. In this scheme, the adaptation procedure is based on exchanged messages containing information on network density and neighbors number. Naumov et al. proposed Connectivity Aware Routing (CAR) [9]; it pre-establishes the routing path leveraging a control message that is sent from the source node all over the minimum delay links to reach the destination node. When the message reaches the destination, it is relayed on all over the reverse path and the route is constructed. Multi-metric techniques introduced more awareness of the network state and tried to palliate to the shortcomings of the Uni-metric ones. The use of Uni-metric dissemination schemes lacks of information on the network state and Multi-metrics schemes have been proposed to cure this. However, for a relatively complete knowledge of the network state, nodes require to continuously exchange specific messages containing information on their speed, heading, link state and position. This induces an overhead and weighs on the network performances which can lead to network performances degradation. In the next section, MUDDS, a complementary work to the approach in [15] will be presented. This approach aims to cures the cracks in the previous work especially avoiding the network disconnection problem that can happen since in [15] only 2-HOP dissemination is performed.

III. Proposed scheme: MUDDS

Researchers focus on reducing the overhead caused by the continuous exchange of information to achieve a global awareness of the network state, either by controlling the network congestion or by tuning up the control messages broadcast frequency. This work presents a novel approach, called Multi-metric Unicast Data Dissemination Scheme (MUDDS). MUDDS is a multi-metric data dissemination scheme based on two primary metrics; (a) PRR; and (b) LA. These two metrics are based on local measurements and every node is supposed to have the ability to compute them. MUDDS operates in two phases; (1) a range/power adaptation phase in which a range adaptation is performed to guarantee a maximum PRR according to the network state in term of congestion and communication density. (2) The messages forwarding phase which is performed based on the LA metric. The use of PRR guarantees reliability on messages forwarding and LA based choice of the forwarder guarantees less hop and aims to avoid the network disconnection problem.

In this paper, we assume that; (a) all vehicles are equipped with 802.11p enabled communication devices as specified in the standard 802.11p specifications and that their output power and receivers sensitivity are known or can be retrieved using their Identity. (b) Signals are subject to the same attenuation in both directions of a particular link. Considering two communicating nodes A and B; if an RSS attenuation measurement is performed in the node B side (respectively A), it will be the same as that measured in the node A side (respectively B). (c) We assume that all vehicles have the ability to compute the PRR in their range; by implementing overhearing technique and by scrutinizing the physical layer.

We define the overhead as the extra type of messages that have to be sent to construct knowledge on the network state; usually called control messages and containing information such as position, heading, link state, etc. We use the communication density (CD) definition as specified in equation 1 [1], a combination of the transmission range, Tr (meter), the messaging frequency, Mf (Hz) and the vehicles density, Vd (vehicle / km road).

$$CD = Mf \times Tr \times Vd \tag{1}$$

As a first approach to expose our ideas on the overhead-free message dissemination scheme for VANETs that meets safety related applications requirements, we present the scheme architecture in Figure I and we detail its operating mode in two phases; (a) the adaptation phase and (b) the dissemination phase.

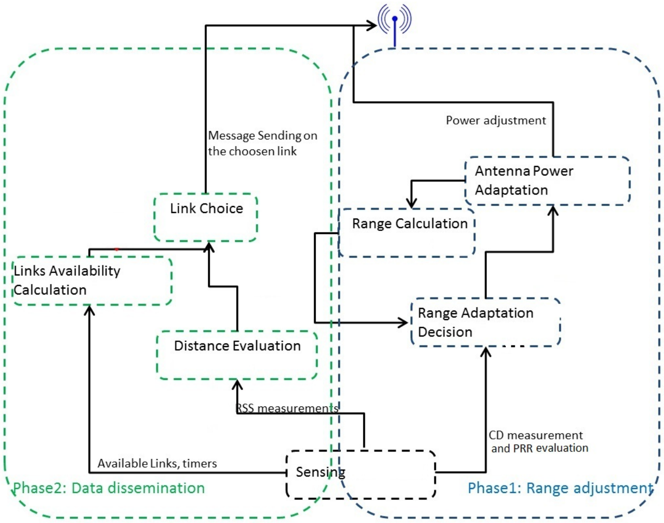

Fig. 1. MUDDS architecture

A. MUDDS adaptation phase

We assume that all nodes have the ability to compute their own PRR and the local CD in their transmission range. As the PRR constitute a good network performances indicator, it was chosen as a metric for MUDDS adaptation scheme. PRR_t value characterizes the maximum achievable PRR considering the actual network state and PRR_{th} characterizes the minimum acceptable PRR expressed by applications constraints (given as entry to the system; e.g. For safety application, we can consider a PRR over 80 percent as sufficient). PRR is highly related to the number of packet losses in the network (see equation 2 where; N_s the number of successfully received packets, N_t the total number of sent packets, and N_l is the number of lost packets). These losses are often due to collisions that can occur in the network. The number of collisions increases when the network is close to its saturation.

$$PRR = \frac{N_s}{N_t} = \frac{N_t - N_l}{N_t} \tag{2}$$

As discussed earlier, our approach is based on the CD metric that characterizes the network state in term of communication density and as proven in [1], for a fixed CD value the network performances are similar. In highly dense network, collisions probability became higher and consequently a high PRR cannot be guaranteed. While, in less dense environments, the number of lost packets is smaller, this maintains an acceptable PRR level.

PRR is inversely proportional to the CD. CD as shown in equation 1 depends on the transmission range, messaging frequency and the vehicles density. So three parameters can have an impact on CD values; (1) Transmission range which depends on the transmission power, receivers sensitivity and the propagation environment, (2) the messaging frequency which was taken into account to reduce the network load and (3) the vehicles density which can also be tuned by modifying the detection range (if the detection range take a maximum value corresponding to the maximum transmission range). An adaptation approach based on the transmission power tuning in order to act on the CD and consequently on the PRR was chosen. Since MUDDS operates locally, modifying the transmission power can have a double effect on CD parameters; reducing transmission power means reducing transmission range and eventually reducing the perceived network density. This has an overall impact on reducing the local CD and consequently increasing the locally perceived PRR. MUDDS adaptation phase operates in two main sub-phases; (1) the sensing phase, (2) the range adaptation phase.

1) Sensing phase: A first step is to collect data on the actual network density, the number of neighbors, their relative distances from the actual node and the maximum achievable range considering the actual transmission power. The sensing component extracts in real-time information to evaluate the CD and the PRR locally. As CD is a mean value, its sensing cadency is potentially lower than the RSS measurements cadency and timestamps has to be specified so that measurements can be matched. RSS measurements are performed every second and PRR evaluation needs more time to collect information and its latency is twice the time. An example of the extracted data structure is shown in Fig. 2.

CD measurement	Timestamp	CD value	
RSS measurements	Timestamp	Vehicle ID 1	RSS value 1
		Vehicle ID 2	RSS value 2
		Vehicle ID 3	RSS value 3
		Vehicle ID n	RSS value n

Fig. 2. Sensed data format

2) Range adaptation phase: The main purpose of this phase is to decide when performing a range adjustment to avoid network congestion and to keep a PRR higher than that is required by applications, PRR_{th}. The range adaptation is only performed locally (every vehicle adapts its own range according to its evaluation of the PRR). According to PRR_t and the PRR_{th} values, an adaptation phase can be initiated in which three decisions can be taken; (a) reducing the transmission power, (b) increasing the transmission power or (c) maintaining it as described in Algorithm 1.

CD measurement, neighborhood and communication on the range information extracted by the sensing phase are used to make such a decision. As shown earlier, changing the transmission range affects the network density in terms of CD and consequently affects the PRR. Reducing transmission range can cause network disconnection in high communication density environments and increases the number of hops which can have a negative effect on the E2E delay. Consequently, MUDDS integrates a dissemination scheme based on a novel metric, LA, to cure that miss-behavior in such conditions and to ensure a minimum E2E delay.

Algorithm 1 Range adaptation

Require: PRR_{th} {PRR threshold} , CD_t {CD measurement at instant t} , $PRR_t = funtion(D_t, Dist_t)$ {computed locally}
  if $PRR_t < PRR_{th}$ **then**
    reduce transmission range according to the desired PRR
  else
    if $PRR_t > PRR_{th}$ **then**
      raise transmission range according to the desired PRR
    else
      maintain the actual transmission range
    end if
  end if

B. MUDDS messages dissemination phase

The dissemination is the second phase of the proposed scheme. In MUDDS, to ensure a minimum number of hops, the farthest vehicle in the emitter vehicle range has a greater priority to forward the message. Neighboring vehicles, by implementing overhearing techniques, detect that the actual message stored in their buffers is forwarded and ignore its transmission. MUDDS dissemination phase can be partitioned in two sub-phases; (a) the election of the possible messages forwarders, (b) the choice of the most reliable link according to the LA metric.

1) Forwarders election phase: In this phase, every node maintains a table containing estimations of the distances between its reachable neighbors. This estimation is based on the RSS measurements, the transmission power knowledge and by applying the right propagation model. Equation 3 [19] shows the distance effect on the signal attenuation using the TwoRayGround propagation model where $H_i, i \in [t, r]$ corresponds to the transmitter/receiver height, $G_i, i \in [t, r]$ to the transmitter/receiver antenna gain, $P_i, i \in [t, r]$ to emitted/received power, *d* to the distance between transmitter, and receiver, and *L* the system loss.

$$P_r = \frac{P_t \times G_t \times G_r \times H_r^2 \times H_t^2}{L \times d^4} \tag{3}$$

Since the distances estimation is made locally; local measurements, it does not need messages exchange and consequently does not involve an overhead.

2) Link choice phase: Lets assume that a link is identified *l(b,t)* ; *b* is the ID of a detected vehicle in the neighborhood, *t* is the associated sensing timestamp. For every vehicle ID b_i, we maintain a timer, t_i, corresponding to the duration of availability of that particular link and a global timer *T*. If a particular link is sensed, its associated timer is incremented by the number of time units that the sensing phase needs. By this we define the link availability rate as a ratio between how long a particular link has been available t_i and the total time *T* as in equation 4.

$$Link\ availability\ rate(l, t) = \frac{t_i}{T} \tag{4}$$

As MUDDS dissemination phase aims to reduce the E2E delay by reducing the hop number with respect to the messages dissemination reliability, the distance between the sender and the possible forwarder was taken into account to give a higher priority to the farthest forwarders. LA (see equation 5 where $distance_i$ is the evaluated distance between the actual node and the selected forwarder, t_i the duration of the link availability, *R* the maximum achievable transmission range, and *T* the total time) metric takes into account the Link availability rate (equation 4) as a good indicator of the link state and the link length (distance between the sender and the possible forwarder). This metric aims to take these two parameters into consideration, choosing the farthest vehicle reduces the hop number and consequently the overall delay. Choosing the most reliable link guarantees the message delivery and avoids network disconnection problem.

$$\begin{aligned} LA_i = distance_i \times availability\ rate_i = \frac{distance_i \times t_i}{T} \\ 0 \leq distance_i \leq R \\ 0 \leq t_i \leq T \end{aligned} \tag{5}$$

Every node has to construct one local table as shown in Table I containing for each link (one link is identified by the two communicating node), its availability rate and its length (here the length is the distance between the two node obtained based on the RSS attenuation measurement). The link having the greatest LA value is considered as the best link in terms of delay and reliability; local reliability is ensured by the adaptation phase and the dissemination phase aims to maintain this reliability and ensure a minimum delivery delay all over the path. In Table I, the node f will be chosen to forward the message since the link identified by (a,f) presents the maximum Link Availability value (138) corresponding to 92 % of availability and up to 150 meters distance from the sender.

TABLE I
EXAMPLE OF LOCAL LINK AVAILABILITY TABLE (NODE A, T=100 TIME UNITS)

Link	a,b	a,c	a,d	a,e	a,f
Link availability duration (time units)	5	30	60	72	92
Availability rate	0.05	0.3	0.6	0.72	0.92
Distance	50	100	150	20	150
LA=Distance*availability rate	2.5	30	90	14.4	138

IV. RESULTS OVERVIEW

In this section, we present the simulations results conducted using NS-2 to compare and evaluate the effectiveness of our approach compared to basic Vehicular Deterministic Access (VDA) and Distributed Coordination Function (DCF). Two main metrics are evaluated; (a) the end-to-end delay, (b) the packet reception rate. As MUDDS 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.

A. Simulation parameters

We simulated an 8 lane highway (4 in each direction) with 10 vehicles per lane. We implemented a 6 levels power adaptation scheme integrating LA metric for link choice over standard VDA discussed in [15]. Simulations parameters are presented in Table II. In this section, MUDDS mean VDA access scheme combined with MUDDS adaptation and dissemination schemes, VDA and DCF mean respectively VDA access and DCF access schemes applied to two-hop neighborhood.

TABLE II
GLOBAL SIMULATION PARAMETERS

Parameter	Value(s)
Messaging Frequency	10, 20, and 25 per second
Vehicle densities	10-100 veh/km/lane
Vehicle velocity	60, 80, 100, 120 km/h
Simulation duration	60 seconds
Transmission rate	6 Mb/s [16]
Transmission power	0.05-2(W)
Radio reception threshold	-90 dBm
Signal propagation model	TwoRayGround

B. Results analysis

1) End-to-end delay: MUDDS performance in term of end-to-end delay was studied and compared to VDA and DCF. Fig. 3 shows that MUDDS presents a slow start compared to VDA in light load conditions. Light load condition means light communication density and the number of packets loss caused by collision is still acceptable, so no adaptation is initiated. In medium and high loaded conditions, MUDDS outperforms VDA due to its capability to prevent congestion and consequently reduce the number of collisions. DCF is outperformed by VDA and MUDDS in both high and low load condition and presents respectively about 46 % and 48 % excess E2E delay.

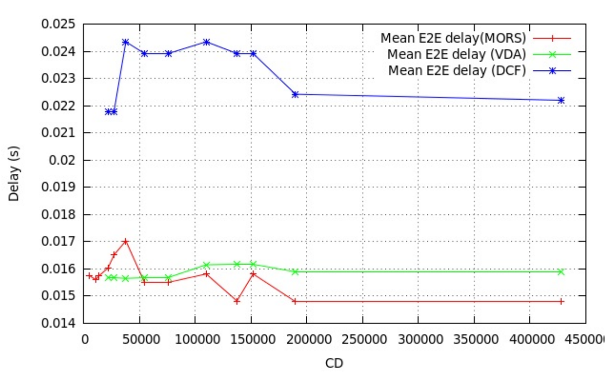

Fig. 3. End-to-end mean delays

2) Packet reception rate: Fig. 4 shows the packet reception rate in various communication densities for MUDDS, VDA and DCF. VDA and MUDDS outperform DCF as they enhance scheduling. MUDDS performance is similar to VDA and outperforms it in medium communication densities conditions. This is due to MUDDS capability to avoid congestion, adapt the communication density and therefore avoid possible packets loss. This supports the previously presented remark that MUDDS is particularly efficient in medium and high communication densities. Fig. 5 shows the impact of MUDDS adaptive behavior on the PRR where every peak corresponds to an adaptation phase.

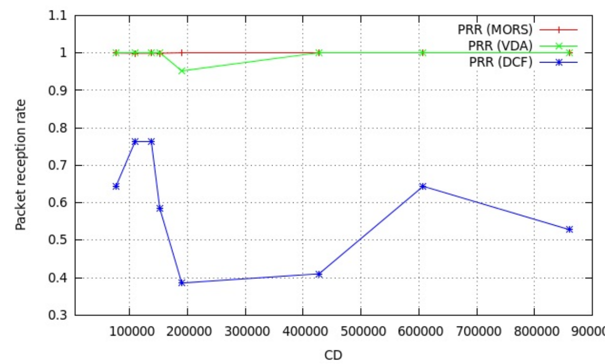

Fig. 4. Packet reception rate (MUDDS,VDA and DCF)

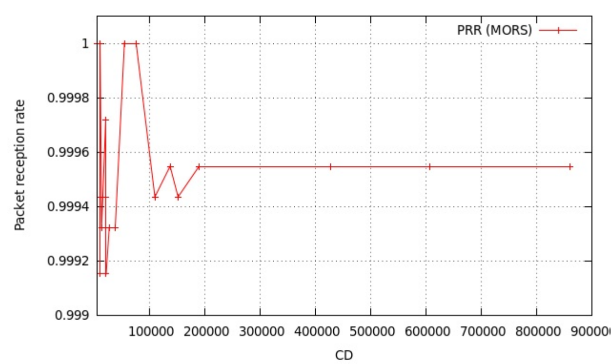

Fig. 5. Packet reception rate (MUDDS)

3) The price of the adaptive behavior: As we introduced an adaptive behavior in MUDDS, we have to measure the impact of such adaptive scheme on the network performances. In MUDDS, an adaptation phase precedes the dissemination phase. Such adaptation involves an additional delay which is presented in Fig. 6 as the power adjustment latency. This additional delay causes a lag in the overall delivery delay. Even with that additional delay, MUDDS outperforms DCF and VDA. Fig. 7 shows the effect of the adaptation scheme on the measured CD, we remark that the adaptation scheme has a deeper impact in highly dense environments which approves the effectiveness of MUDDS in high communication densities.

Fig. 6. MUDDS power adjustment latency and E2E delay

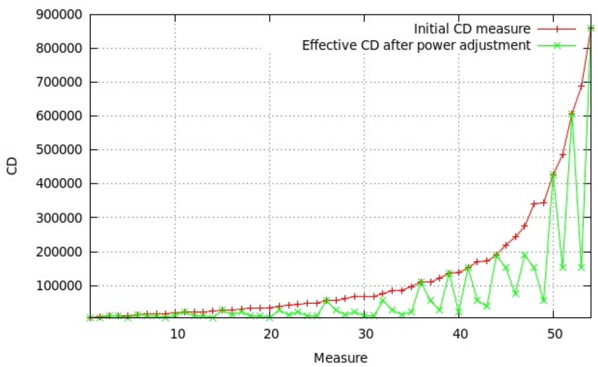

Fig. 7. Power adjustment effect on the CD

V. CONCLUSION AND FUTURE WORKS

In this paper, we present an adaptive overhead-free dissemination scheme for VANETs. MUDDS uses local RSS and CD measurement to dynamically adapt the transmission power and introduces a new metric in which is based its dissemination phase. MUDDS does not need a continuous exchange of information and therefore does not involve an overhead. Using simulation, we show that MUDDS outperforms VDA and DCF in terms of End-to-end delay in high communication densities and in terms of PRR in medium communication densities. MUDDS is effective for highly congested environments where the high communication density results in high number of packets collision. We plan to conduct more simulations especially in highly congested environments such as urban environments. These additional tests will support MUDDS effectiveness.

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