Advanced Activity-Aware Multi-Channel Operations with IEEE 1609.4 in VANETs for Vehicular Clouds

Yassine Maalej[1], Ahmed Abdel-Rahim[1], Mohsen Guizani[1], Bechir Hamdaoui[2], Elyes Balti[1]

[1]University of Idaho, Moscow, ID, USA [2]Oregon State University, Corvallis, OR, USA

Abstract*—The Dedicated Short Range Communication (DSRC) technology has been used in Vehicular communication to enable short-lived safety and non-safety applications based on Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications in Vehicular Ad hoc Networks (VANETs). VANETs are used by spontaneously creating a wireless network of vehicles with high mobility and fixed infrastructure. It presents numerous challenges for protocols and applications design to meet low latency and high data rate requirements of vehicular applications. With the under-utilized advanced computation, communication and storage resources in On-Board Units (OBUs) of modern vehicles, Vehicular Clouds (VCs) are used to manage coalitions of affordable resources in Vehicles being in the same area in order to host infotainment applications used by other vehicles on the move. To better serve non-safety applications, it is highly desirable that VCs take advantage of the maximum usage of Service Channels (SCHs) while taking into consideration the V2V safety messages exchanged between Vehicles over the Control Channel (CCH). In this paper, we introduce an Advanced Activity-Aware (AAA) scheme for Multi-Channel Operations based on 1609.4 of the MAC Protocol in Wireless Access in Vehicular Environments (WAVE) standard. The AAA aims at dynamically achieving an optimal setup of Control Channel Interval (CCHI) and Service Channel Interval (SCHI) by reducing the inactivity interval while maintaining a default Synchronization Interval (SI) between all vehicles. We evaluate the performance of our proposed AAA scheme through real-time simulation of vehicular cloud load and VANET communications using ns-3. The simulation results indicate that our proposed scheme increases significantly the throughput of the VC and reduces the average number of dropped Virtual Machines (VMs) and the average delay of uploaded packets of non-safety applications from the VC to the Road Side Unit (RSU), while maintaining a V2V safety broadcasting similar to that of the IEEE 1609.4 Standard for Multi-Channel Operations.

***Index Terms*—DSRC, V2V, V2I, VANETs, VCs, WAVE, IEEE 1609.4, VM, safety applications, non-safety applications.**

I. Introduction

Vehicular Communication and Cloud computing are the corner stones for building smart cities with intelligent transportation management, on the air infotainment applications and safer roads. The idea behind VCs is to be deployed on VANET and to host applications that are frequently requested and used. Virtualized resources of vehicles and RSUs on streets offer a promising environment to place these applications. The reliability of the vehicular network and the cloud are of paramount importance because of the complex challenges related to the need to increase the offloading data from the cloud, safety of vehicles and the rapidly changing topology of the network. Vehicles are mounted with Dedicated Short Range Communication (DSRC) [1] standard that was coined by the FCC (Federal Communication Commission) [2] to take place over a dedicated 75 MHz spectrum band around 5.9 GHz in the USA [3] and partitions the bandwidth into seven channels of 10 Mhz each. One control channel CCH number 178 that is used to serve safety related beacons and event-driven applications. Six Service Channels SCHs (172,174,176,180,182,184) to serve non-safety applications. Safety applications are time critical applications that are based on V2V communications, while non-safety applications rely mostly on V2I communications and include V2V communications in case of infrastructure coverage limitations. VANETs deployments are supposed to guarantee the reliability of V2V safety messages and expected to consolidate available resources in a VC platform to host applications with the lowest downtime on the client side during Virtual Machine Migration (VMM).

The outline of the contributions of this paper relative to the recent literature can be summarized as:

- Awareness of channel inactivity and dynamic interval switching based on the average effective interval utilization.
- Improvement of the connectivity of the VC by reducing V2I end-to-end delays through maximizing the SCH utilization.
- Reduction of the average number of dropped Virtual Machines (VMs) during migration by enhancing the throughput of the VC and improving of the reliability of offered services by reducing the end-to-end delay of packets from vehicles to the RSU.

The remainder of this paper is organized as follows. Section II presents the related work on VCs and performance evaluation of the DSRC communication. IEEE 802.11p MAC and IEEE 1609.4 Multi-Channel Operations are discussed in section III. Section IV presents the proposed Advanced Activity-Aware (AAA) immediate Multi-Channel Operations that maximizes the utilization of SCH. Section V reports the simulation results of the metrics of applications in VANET and in VC in which the impact of the developed AAA scheme is evaluated. In Section VI, we conclude the paper and provide recommendations for future research directions.

II. Related Work and Motivation

The Internet of Vehicles (IoV) includes different types of VCs to perform multiple non-safety and/or commercial applications, which provide a great market opportunity and rising challenges to make the technology more cost effective. The VC should be capable of combining and managing the resources of connected vehicles and the infrastructure's micro data centers. VCs are formed by incorporating cloud-based services into VANETs and they are considered as non-conventional cloud environments that require efficient utilization of computing, storage resources and handle communication and networking constraints. VCs can be implemented by consolidating the OBUs of geographically co-located parked vehicles [4]. This kind of cloud is the easiest to mount since the vehicles are not mobile and we can profit from all DSRC bandwidth to be used for the cloud including all the SCHs and also the CCH because there is no need for vehicles to exchange safety messages while parked. Olariu *et al.* [5] defined VCs linked via wires or cellular towers to the Internet to a backbone that is used for the management and orchestrating of the cloud system. It is not considered cost efficient since cloud resources are rented and neither the affordable microdatacenters of RSUs in roads nor in vehicles are used. In [6] the authors propose forming a vehicular cloud by using the microdatacenters in the RSUs so that every RSU offers its capabilities to host vehicles' infotainment applications. The most challenging VC is formed by autonomously merging the OBUs of the moving vehicles to offer non-safety services [7]. This kind of pure VC is the most complex to manage because of the high mobility of vehicles which leads to not only to an unpredictable availability of computational resources but also variable performance of V2V communications over CCH and V2I communications on SCH. Dual-radios are used per vehicle in [8] with one radio continuously used for CCH and the other one continuously used for SCH. Although it avoids the necessity of Multi-Channel Switching and increases both of the channel utilization, but comes with high interference cost caused by the adjacent channels. Reference [9] proposes an adaptive independent channel switching scheme that allows each vehicle to switch to SCH as soon as sending its safety related packets on CCH ends. The developed solution improves the usage of SCH in every SI and consequently the performance of the VC but deteriorates the reliability of safety messages because not all the vehicles will reside on the CCH at the same period during different CCHI. This means that vehicles that switch early to SCH will miss all the safety messages sent by their neighbors. In [10], the authors adapted the Minimum Contention Window of the CCH's Access Classes based on a given CCHI that satisfies a certain successful transmission rate of safety application, Vehicle density, communication range changes, safety messages sizes and rate. It has a limitation regarding the use of static CCHI and comes with high instability of the network since vehicles adapt their communication ranges very often. The scopes of most of the studies that are related to improving the delay and successful transmission of either safety related messages on CCH or non-safety applications on SCH. To the best of our knowledge, this is the first research that investigates additional complexity of minimizing the CCHI without loosing the reliability of safety messages and maximizing the SCHI that will to be used for not only sending non-safety related packets to the outside world but also for VMM from vehicles to the RSU.

III. Wireless Access in Vehicular Environments

A. *WAVE 802.11p MAC*

Many Medium Access Control (MAC) protocols in 802.11p are developed in the literature review that are based on Wireless LANs of earlier standards. VANETs are characterized with rapidly changing network topology due to vehicles' mobility, which makes the medium access very challenging. Time Division Multiple Access (TDMA) [11], Frequency Division Multiple Access (FDMA) [12] and Code Division Multiple Access (CDMA) [13] have hard feasibility because the coordination is difficult to permanently associate time slots, frequency channels or codes with vehicles. The IEEE 802.11p MAC employs Carrier Sense Multiple Access (CSMA) with Collision Avoidance (CSMA/CA) protocol [14] that is considered the best adapted by VANETs. The IEEE 802.11p in WAVE can only transmit packets on one channel, it offers a continuous access mechanism [15] to the CCH and SCH for vehicles to send both their safety and non-safety packets, as illustrated in Fig.1.

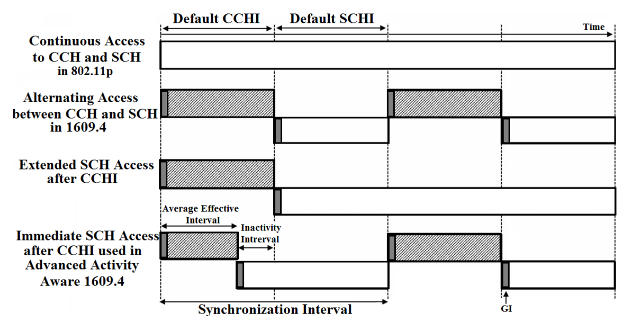

Fig. 1: Wave different Channel Access Mechanisms

DSRC standard recommends that, for a SI that is equal to 100ms, vehicles should visit the CCH to exchange their different types of status messages with the neighboring Vehicles [10]. The IEEE 802.11p protocol offers Quality of Service (QoS) differentiation between the applications that will be transmitted on either the CCH or in the SCH by supporting the contention-based Enhanced Distributed Channel Access (EDCA) mechanism [15]. EDCA offers four access classes using one transmission queue for each, as shown in Fig.2, with different Arbitration Inter-Frame Spacing (AIFS) period, minimum and maximum Contention Windows (CWs) to differentiate between low and high priority traffic. To support channel switching and coordination procedures, IEEE 1609.4 standard for Multi-Channel Operations [16] is defined on top of the IEEE 802.11p MAC as shown in Fig.2.

B. *WAVE Multi-Channel Operations of the 1609.4 Standard*

The IEEE 1609.4 standard is developed for WAVE to support Multi-Channel wireless radio operations. It provides DSRC frequency band coordination and management with channel switching and routing of multiple connection access. It adopts IEEE 802.11p MAC and Physical Layer (PHY) specifications. As shown in Fig.1, IEEE 1609.4 standard describes a concept of channel intervals in which time is divided into alternating

CCH and Service Channel SCH intervals used respectively to send safety and non-safety messages. One of the major issues with the 1609.4 standard, especially with non dense VANETs, is the channel utilization because every vehicle is supposed to stay tuned to CCH (resp SCH) during CCHI (resp SCHI) independently whether or not it has messages to send or others are sending. In general, it is expected to have small channel busy time [17] for low density networks during safety message transmissions. It is a good motivation to characterize the network parameters and satisfy an advanced time share between the VANETs' messages and Cloud applications especially in case that we have a VC that should offer services, handle task placement and virtual machine migration from vehicles before leaving the network.

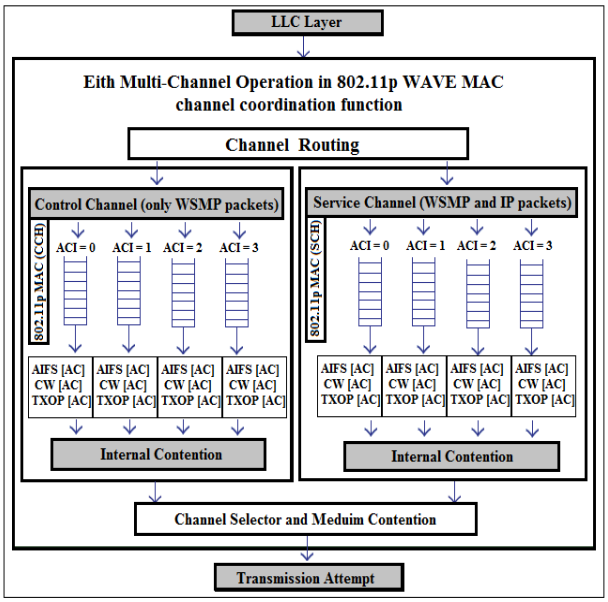

Fig. 2: IEEE 1609.4 MAC with Multi-Channel Operations

IV. Advanced Activity-Aware Immediate Multi-Channel Operations

In this section, we describe the variables of the problem and introduce the steps of the proposed algorithm of the AAA Multi-Channel Operations Scheme. The AAA is composed of two major parts of determining the effective CCH utilization and updating MAC interval timers. While vehicles are moving under the RSU coverage area, they may get close or far from each other, which will lead to a changing end-to-end delay of the exchanged BSM messages and consequently a changing number of transmitted packets during the CCHI. In addition, new vehicles entering the VC will require not only sending VC applications but also to broadcast their beacon BSM. Finding the average end-to-end delay and the number of exchanged BSM is the key part to dynamically evaluate whether or not the used CCHI can be reduced. We consider a preliminary step in which vehicles collect characteristics about the V2V communication and then the RSU executes the AAA algorithm at the beginning of every UTC second. The number of generated BSMs in one SI by each vehicle is determined by Eq.1 and these messages are supposed to be ready at the beginning of the GI of every CCHI.

$$NG_{BSM} = RG_{BSM} * SI \tag{1}$$

At every CCH access during CCHI, vehicles broadcast their safety related messages. The number of BSM packets sent by a vehicle v_h is equal to the difference between the generated messages and the queued ones. It is expressed as follows:

$$Sv_h = NG_{BSM} - Qv_h \tag{2}$$

The average end-to-end delay of the successfully received BSMs sent from neighbors is calculated by every vehicle. It can be found for a vehicle vh as:

$$Dv_h = \frac{\sum_{\substack{i=1 \\ i \neq h}}^{N_V} \sum_{j=0}^{N_{ih}} t_{Rijh} - t_{Sijh}}{R_{vhBSM}} \tag{3}$$

The vehicles update the RSU about their average number of sent BSMs and the average end-to-end delay of the BSMs that they have received as described is Algorithm 1. The RSU calculates the average effective CCH utilization equal to the average end-to-end delay of one BSM in the network multiplied by the average number of sent BSM during the current CCHI in the last second. Since we want to improve the VC performance, we will keep the CCHI always less or equal to the default CCHI. The inactivity interval is equal

TABLE I: SYMBOLS AND NOTATIONS

Varaible	Description
N_V	Total Number of Vehicles
ST	Total Simulation Time
SI	Default Synchronisation Interval
N_{Sync}	Number of SIs in Total Simulation Time
SI_i	Current Snchronisation Interval
I_{CCH}	Inactivity Interval of CCH in CCHI
$CCHI$	Current Control Channel Interval
$SCHI$	Current Service Channel Interval
U_{CCH}	Average effective utilisation of CCH in CCHI
RG_{BSM}	BSM packet generation rate
RG_{VC}	VC non-safety application packet generation rate
NG_{BSM}	Number of generated BSM messages per vehicle
NG_{VC}	Number of generated VC applications packets per vehicle
S_{vi}	Number of BSM sent by vehicle vi
D_{vi}	Average end-to-end delay of all BSMs received by vi
Q_{vi}	Number of BSM queued packets of vi
Qvi_{VC}	Number of VC queued packets of vi
Rv_{iBSM}	Number of BSM received of vehicle vi
t_{Sijh}	Time j^{th} BSM is sent by vi and received by vh
t_{Rijh}	Time j^{th} BSM sent by vi is received by vh
N_{ih}	Total number of BSMs sent by vi and received by vh
$tSVC_{ijRSU}$	Time when packet j is sent from vi to the RSU
$tRVC_{ijRSU}$	Time when packet j sent from vi is received by RSU
$NiRSU$	Number of VC packets sent by vi and received by RSU
S_{V2V}	Average number of BSM messages sent by all the vehicles
S_{VC}	Average VC packets sent by vehicles to the RSU
D_{V2V}	Average end-to-end delay of BSM message
D_{VC}	Average end-to-end delay of VC packets
$DCCHI$	Default Control Channel Interval
$DSCHI$	Default Service Channel Interval

to the difference between the CCHI and the average effective CCH utilization time. In case of inactivity in CCHI, the SCHI will be increased to maintain the default SI equal to 100 ms. Algorithm 1 describes in the first part of calculating the average end-to-end delay between of BSM from one synchronization time to another as well as the average number of all the BSMs sent.

Algorithm 1 Advanced Activity-Aware Multi-Channel Operations

Result: Adjusted CCHI and SCHI

$N_{Sync} = \frac{ST}{SI}, SI_i = 1$

while $SI_i < N_{Sync}$ **do**

  if *Current Time != UTC second* **then**

    $S_{V2V} = \frac{S_{V2V} + \sum_{v_h=1}^{N_V} Sv_h}{1+N_V}$

    $D_{V2V} = \frac{D_{V2V} + \sum_{h=1}^{N_V} D_{vh}}{1+\sum_{v_h=1}^{N_V} Rv_{h\,BSM}}$

  else

    {Average Effective CCH Utilization}

    $U_{CCH} = S_{V2V} * D_{V2V}$

    {Inactivity Interval in current CCHI}

    $I_{CCH} = CCHI - U_{CCH}$

    if $U_{CCH} < D_{CCHI}$ **then**

      {*Update MAC Interval Timers* }

      $CCHI = U_{CCH}$

      $SCHI = SCHI + I_{CCH}$

      { *The* NG_{VC} *generated at the new SCHI*}

      $NG_{VC} = RG_{VC} * SI$

      {*Increased* S_{VC} *in new longer SCHI*}

      $S_{VC} = \frac{S_{VC} + \sum_{h=1}^{N_V} NG_{VC} - Qv_{iVC}}{N_V+1}$

      {*Reduced* D_{VC} *in the new longer SCHI*}

      $D_{VC} = \frac{D_{VC} + \sum_{i=1}^{N_V} \sum_{j=0}^{NiRSU} tRVC_{ijRSU} - tSVC_{ijRSU}}{1+\sum_{i=1}^{N_V} \sum_{j=0}^{NiRSU} tRVC_{ijRSU} - tSVC_{ijRSU}}$

    else

      {*The CCHI is not sufficient for this number of vehicles and BSM rate*}

      $CCHI = D_{CCHI}$

      $SCHI = D_{SCHI}$

    end

    $S_{V2V} = 0$

    $D_{V2V} = 0$

    SI_i= SI_i + *1*

  end

end

V. Simulation Results and Comparison

Fig.3 is a screenshot of the VC simulated by ns-3 that is formed by an RSU in constant position and a random number of moving vehicles in way point mobility with random speed. Safety messages related packets are generated per each vehicle once every 100ms corresponding to the beginning of the Guard Interval of every CCHI. We consider also the same packet generation rate of the non-safety applications, for the VC, that are ready in each vehicles at the beginning of the Guard Interval of every SCHI. We consider only V2V periodic BSMs with equal packet size of 200 Bytes and VC non-safety applications with packets equal to 1500 Bytes. We use equal priority between packets using the background traffic (BK) access category in EDCA for the CCH. Fig.4 shows that in zone Z0, where few number of distant vehicles are introduced to the network randomly, average end-to-end delay of V2V safety high for AAA scheme that is almost equal to the one offered by default IEEE 1609.4 even though that the CCHI was reduced enormously as shown in Fig.8. When the number of vehicles gets larger, in zone Z1, the inter-distances between vehicles get smaller and the CCHI gets bigger, as shown in Fig.8 to allow more vehicles to successfully send their safety related messages. The average end-to-end delay of the VC is improved in low dense VANETs, as described in Fig.5. As long as the number of vehicles increases, more BSM are needed to be sent and so the CCHI gets bigger, which induces the reduction of the Inactivity Interval and consequently decrease of SCHI, as described in Fig.8 describe, and causes an increase of the average end-to-end delay of VC applications. The AAA scheme for Multi-Channel Operations shows almost the same successful received number of BSMs and V2V throughput as in 1609.4, as shown in Fig.6. This can be compared to the IEEE 1609.4 with static interval timers, even though the CCHI is significantly reduced as shown in Fig.8.

TABLE II: Parameters of the simulation

Parameters	Values
Number of Vehicles	5 - 50
Number of RSUs	1
Simulation Time	1000 ms
Synchronisation Interval (SI)	100 ms
Virtual Machine size	500 kbits
Transceiver Communication Range	200m
RSU area	50*50m
Default SCHI and CCHI	50 ms
Default Guard Interval (GI)	4 ms
VC application packet size	1500 Byte
VC application packet generation rate	10 Hz
BSM packet size	200 Byte
BSM packet generation rate	10 Hz
CCH and SCH Bandwidth	10 Mhz
Modulation and Data rate	QPSK 6 Mbps
EDCA Access Class	Background Traffic (BK)
CWmin of BK	15
CWmax of BK	1023
AIFSN of BK	9
Number of SCH and CCH	1
Propagation Model	Nakagami

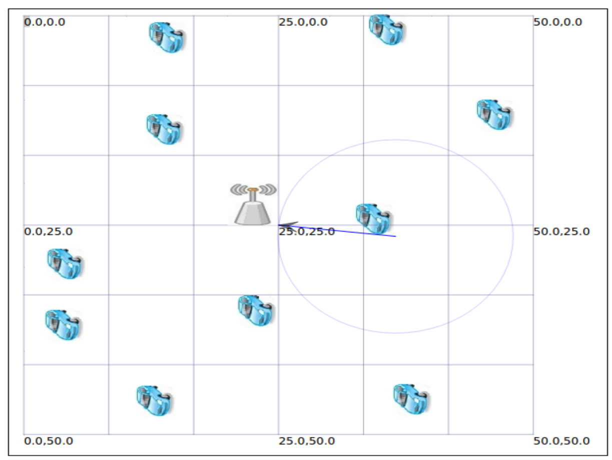

Fig. 3: VC with RSU gateway Simulation in NS3

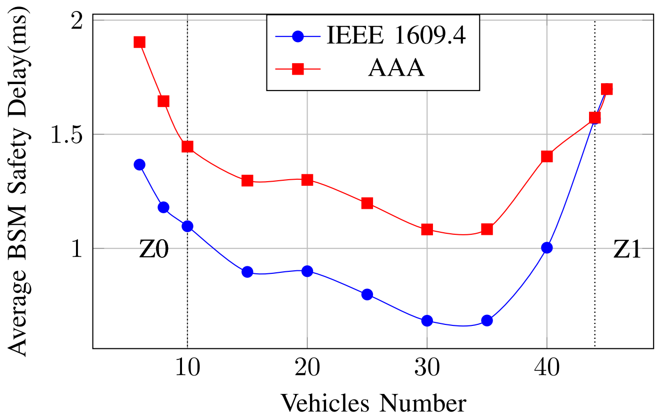

Fig. 4: Average end-to-end delay of BSM safety messages versus number of vehicles

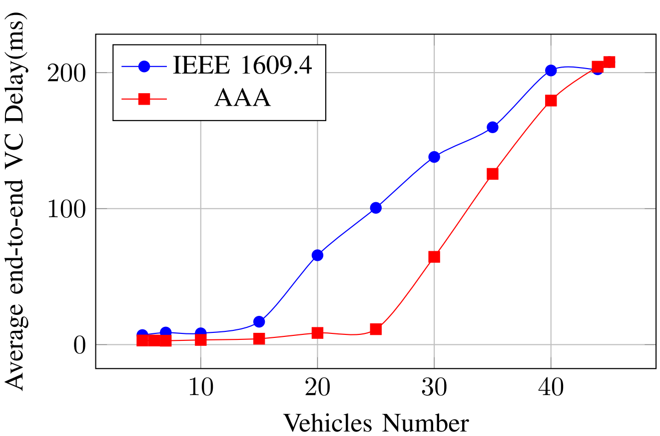

Fig. 5: Average end-to-end delay in VC of Non-safety messages versus number of vehicles

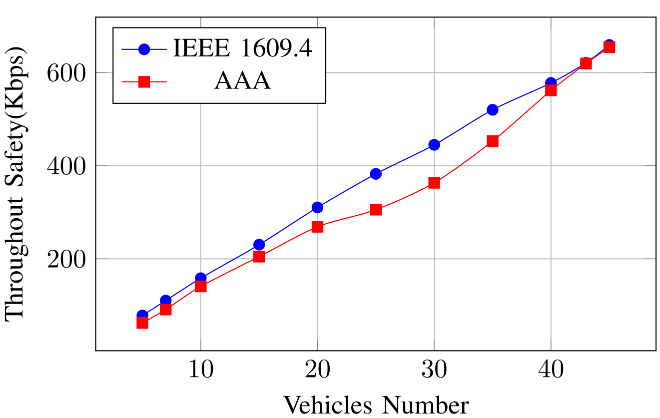

Fig. 6: Throughput of V2V BSM safety messages versus the number of vehicles

There is a clear and significant improvement in the throughput of the VC when using the AAA Multi-CHannel Operations scheme over the static 1609.4 as shown in Fig.7. The improvement is due to considering that the CCHI is minimized by the inactivity interval that is bigger in non dense VANETs, which procure an extended time to the SCHI for the VC applications. Therefore, more vehicles will find slots in the CW to send packets successfully, which consequently improves the throughput of the VC.

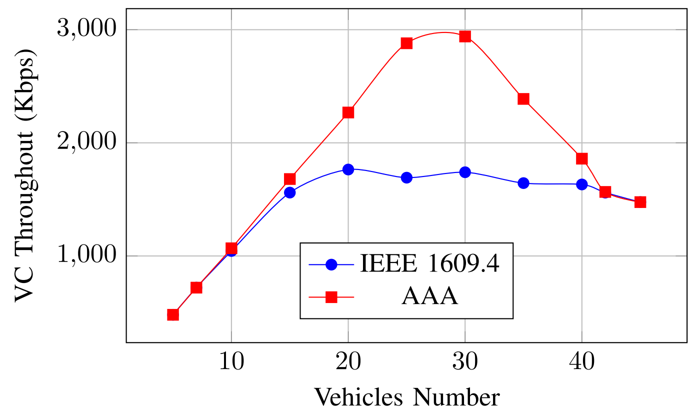

Fig. 7: VC Throughput of Non-Safety applications versus number of vehicles

Fig.8 describes the effect of the AAA scheme in finding the inactivity interval and adapting the interval timers of 1609.4 by reducing the CCHI for the BSM and increasing the SCHI for VC usage.

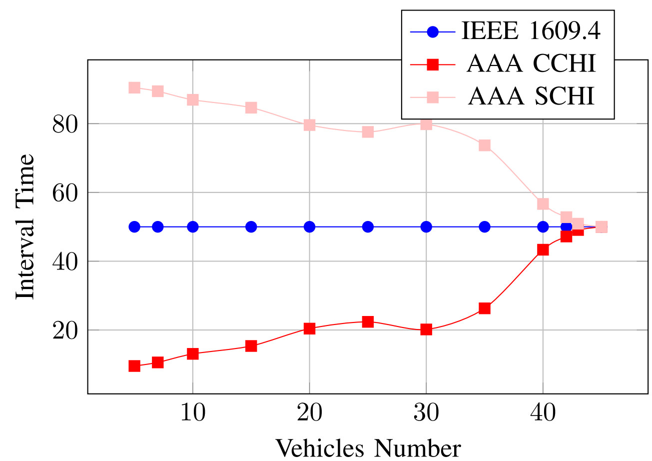

Fig. 8: Channels Intervals Adjustment of AAA and 1609.4 versus the number of vehicles

The average throughput of non-safety applications in VC per vehicle is formulated in Eq.4 as follows:

$$Th_{ij} = \frac{Th_{VCij}}{j} \tag{4}$$

where Th_{VCij} is the throughput of the VC under the i^{th} mode either IEEE 1609.4 or AAA scheme and with *j* vehicles. We will consider the scenario of a vehicle that has a total of T_{VMsize} = 500kbits as the size of all its VMs to be migrated to the RSU. The size of the packets is maintained equal to 1500 Bytes similar to that of the studied to compare AAA to 1609.4. The average percentage of dropped VMs at instant t(s) from the beginning of migration is defined as:

$$AVM_t = 1 - \sum_{k=0}^{t} \frac{T_{VMsize} - k * Th_{VCij}}{Th_{VCij}} \tag{5}$$

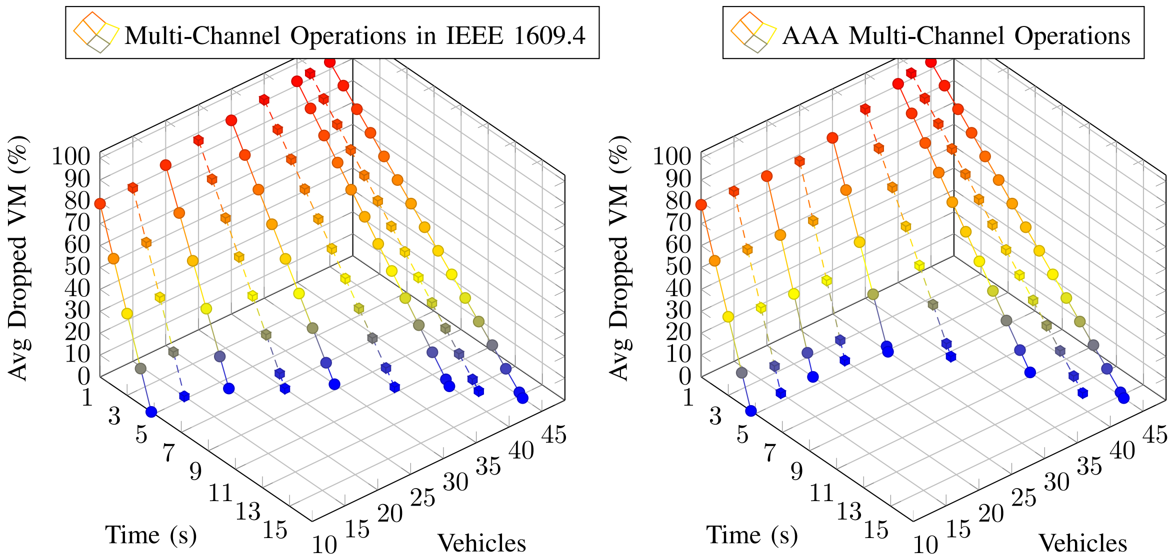

Fig. 9: Average Percentage of Dropped VMs in different netwrok density versus time

Fig.9 illustrates the progress in time of the average percentage of dropped VMs during migration from a vehicle to the RSU in different networks densities. In comparison with IEEE 1609.4, the AAA guarantees a reduced average number of dropped VMs and that is caused by its improvements on the throughput of the VC. AAA gives the chance for a vehicle to successfully migrate all its VMs in less time than it takes in the IEEE 1609.4, which improve the probability of not having a downtime of the applications in the client-side.

VI. Conclusion

The future of the IoV is considered to be dominated by the reliability of VANETs in increasing the safety of vehicles and the performance of the virtualized VC in improving the driving experience. As opposed to traditional Clouds, VC is a more dynamic environment because of the mobility of the physical servers in the OBUs, namely the connected vehicles. In this paper, a study is developed regarding the improvement of the MAC interval timers for accessing DSRC channels to enhance the VC throughput, applications delays and average VMM. To this end, an Adaptive Activity-Aware Multi-Channel Operations is developed to operate in two modes of collection of VANETs V2V communication performance and dynamically adapting the interval timers of the 1609.4 Mutli-Channel Operations. The proposed scheme, aiming at improving the V2I communication for the VC, is evaluated using real time ns-3 simulations of a VC built on top of a moving VANET. Simulation results confirm that the AAA immediate access exhibits the highest performance of the VCs while guarding similar performance of V2V safety broadcasting. This study can be extended by studying efficient task placement of non-safety applications in distributed VC by determining to which cloud the AAA can offer better performance that satisfy the requirements of the tasks.

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