An Efficient Service Channel Allocation Scheme in SDN-enabled VANETs

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***Abstract*—Providing infotainment services in Vehicular Adhoc Networks (VANETs) is a key functionality for the future intelligent transportation systems. However, the unique features of vehicular networks such as high velocity, intermittent communication links and dynamic density can induce severe performances degradation for infotainment services running on the six Service Channels (SCHs) available in the Dedicated Short Range Communication (DSRC). Although, the Wireless Access in the Vehicular Environment (WAVE) has been proposed for VANETs to support these applications and guarantee the QoS by proposing four different access categories, no service channel scheme has been proposed to ensure fair and interference-aware allocation. To fill this gap, in this work we propose ESCiVA, an Efficient Service Channel allocation Scheme in SDN-enabled VAnets to balance service traffic on the six SCHs and mitigate interferences between services provided on adjacent channels. Extensive simulation results confirm that ESCiVA outperforms the basic SCH allocation method, defined in the WAVE standard.**

I. Introduction

After more than a decade of development, VANETs have reached a mature stage and are ready to roll-out with the aim of offering safer and more comfortable driving. A first milestone of the realization of VANETs, was the allocation of the Dedicated Short-Range Communication (DSRC) for automotive use in 1999. Notably, the Federal communication Commission (FCC) in US has allocated 75 MHz of the DSRC spectrum at 5.9 GHz to be exclusively used for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications [1]. The overall bandwidth is divided into seven channels. A single shared control channel 178 (CCH) is used for safety-relevant messages and control frames delivery (beacons, vehicle status and service announcement). In addition, six service channels (SCHs) are dedicated for a wide variety of infotainment services.

Another milestone for the realization of VANETs was the definition of the IEEE802.11p standard [2], an amendment of the IEEE802.11 protocol aiming to cope with frequent link disconnections, highly dynamic networks and multi-hop communications. The IEEE802.11p standard defines only PHY and MAC layer. The reference architecture in USA, called WAVE (Wireless Access for Vehicular Environment) [3], is a set of standards developed by the IEEE1609 working group. This architecture has a major focus on the multichannel wireless operation which is supported on the top of the IEEE802.11p MAC by the IEEE1609.4 MAC extension. Typically, in the WAVE architecture, a service provider (SP) which can be static (RSU) or mobile (vehicle), periodically broadcasts WAVE Service Advertisements (WSA) messages in the CCH. Vehicles listening to the CCH and interested in the advertised service should switch and synchronize to the SCH where the service is made available. Subsequently, channel allocation is very challenging, especially with mobile providers, due to several factors:

- *Spectrum scarcity*: the low number of available SCHs increases the probability of interferences and collisions between concurrent transmissions. Indeed, under high density network condition, service channels can quickly become severe saturated and thus, throughput can be drastically reduced. In such situation, some services may be prevented from operating on SCHs;
- *Provider mobility*: mobile provider can jeopardize the SCH selected by other providers that were not in its radio coverage range. Hence, mobility accentuates interferences and non-well balanced traffic load on SCHs;
- *Lack of a central authority in the network*: VANETs are dense networks with highly dynamic topology. A centralized control entity is crucial to orchestrate and coordinate channel allocation among several SPs.

In addition, the IEEE802.11p standard does not provide any mechanism for assigning SCHs to different providers. To this end, two main approaches were proposed in literature: one centralized, and the other distributed. In centralized solutions [4], [5], the infrastructure (RSUs) is in charge of channel allocation. In [4], the RSU divides the region into rectangular clusters. In each cluster, a time-slotted access is used. However, this approach is evaluated in sparse traffic conditions. Wang et al. [5] assume that the RSU is located in intersections and is equipped with 7 radio transceivers, each one operating in a different channel, which is rather an expensive and not feasible solution.

Several distributed approaches were proposed either to maximize throughput on SCHs [6], [7] or ensure fairly balanced channel occupation [8], [9]. In [7], Dynamic Service-Channels Allocation (DSCA) strategy assigns dynamically SCHs to service providers. Each vehicle willing to provide a service during the next SCH Interval (SCHI), calculates the expected throughput for every SCH before joining it based on the current number of users for each type of traffic priorities.

Campolo et al. [8] aimed to set up channel-disjoint Wave Basic Service Set (WBSS). Two incremental solutions were proposed: a proactive gossiping approach that allows SPs to select a SCH based on the occupancy of the SCHs reserved by providers at $1-hop$ distance. When two SPs have overlapping WBSSs, a reactive gossiping approach is used. An intermediate provider sends a channel collision warning messages that announces to SPs in conflict the owner of the channel. Other providers should switch to a different SCH. To select the least occupied SCH and guarantee a fair access, Frigau et al. in [9] proposed a novel architecture where SCHs availability varies according to the time (synchronization interval) and the geographic position (zone of interest). To transmit data, a vehicle determines the default channel linked with its zone of interest, then checks its availability by analyzing information in the received beacons.

The traditional rigid architecture designed for VANETs is approaching its limits, and can no longer keep up with the emerging and highly dynamic services the citizens are asking for. Therefore, the research community has focused on seeking novel solutions that allows to handle network resources in a more efficient manner. To this end, the *Software Defined Networking* (SDN) paradigm has been proposed in VANETs to break the stalemate of a centralized intelligence [10]. SDN can ensures better flexibility and resources utilization. Indeed, a controller, implemented in the infrastructure, having a holistic overview of the network and the available spectrum resources, can wisely decide for each type of service/traffic which channel to use at each time. Thus, the existence of central authority avoids conflicts and interferences and ensures traffic load balancing among different service channels. A first attempt to investigate how SDN can handle spectrum management was carried out in [11]. A central controller manages spectrum allocation across different Access Points (APs) to mitigate interferences and conflicts. A local manager, implemented in each AP, is responsible for application traffic scheduling and its spectrum configuration. Nevertheless, none of the above mentioned works tackle the problem of SCHs selection and allocations to SPs within the specific context of SDN-enabled VANETs.

In this paper, we propose a load-balancing and interference-aware SCH allocation scheme, ESCiVA that is orchestrated by SDN controllers, implemented in the infrastructure. Our scheme enhances the standard WAVE SCH selection method, simply consisting in selecting the first available channel. In addition, while the previous studies assume the existence of a SouthBound Interface (SBI) between the central controller and the nodes, no standardized SBI for mobile and wireless networks is available yet. For this reason, in our approach we adopt the messages already available in IEEE802.11p/WAVE VANETs (i.e., beacons and WSAs messages) to collect information about network topology, and exchange SCH requests and SCH schedule between the service providers, and the RSU controllers. By doing so, our solution is feasible and can be implemented in already deployed IEEE802.11p/WAVE networks. The proposed scheme allows to fairly use all the 6 SCHs, avoid interferences between services made available on adjacent channels, and also interference on the same channel, when assigned to different providers, moving in overlapping areas.

The remainder of the paper is organized as follows. Section II describes the multi-channel operation in WAVE/IEEE802.11p enabled networks and the basic scheme of SCHs allocation. The ESCiVA Algorithm, with its underlying architecture, and the modified WSA messages is presented in detail in Section III. Results of the performance evaluation conducted with extensive simulations are described in Section IV. Finally, concluding remarks are drawn in Section V.

II. Technical Background

A. Muti-channel operation in DSRC

V2V and V2I communications take place in the 5 GHz dedicated spectrum. In particular, in USA, 75 MHz (5.85-5.925 GHz) were allocated for traffic exchange in vehicular networks. Channel 178 is used as CCH while the six other channels are SCHs. Among them, two SCHs are dedicated to specific applications: the channel 172 is exclusively assigned to V2V safety applications while the channel 184 is used for higher power public safety applications. The presence of multiple channels can enhance the resources utilization by offloading traffic from a congested SCH to less congested one. Besides, multiple SPs can operate simultaneously in different channels without interferences.

The 1609.4 standard in WAVE coordinates the multi-channel operation of single radio vehicles. One of the main coordination mode is the alternating access mode where channel access time is divided into Synchronization Interval (SI) of 100 ms. The SI consists in a pair of a CCH and SCH intervals, as depicted in Figure 1. Vehicles must tune on to CCH on regular basis (each 100 ms) to monitor safety messages and WSAs. Optionally, vehicles switch to one SCH during the SCH intervals (50 ms) to receive the service advertised during the CCH interval. A Guard Interval (GI) is defined at the beginning of both the CCH and SCH intervals (SCHI) with typical values between 4 and 6 ms. GI accounts for the radio switching delay and the time synchronization error.

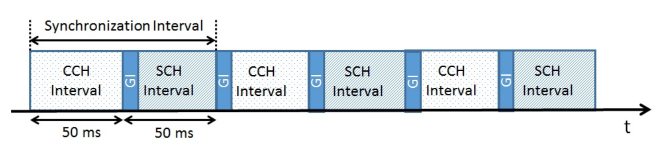


Fig. 1. Channel alternating mode in IEEE1609.4

Besides the alternating channel switching scheme, the IEEE1609.4 standard specifies additionally three channel access schemes: 1) the continuous scheme where a vehicle tunes always his transceiver to the CCH to receive safety services; 2) immediate access scheme where nodes initiate their communications on the selected SCH immediately without waiting for the next SCHI and finally; 3) the extended access scheme where nodes do not switch to the CCH and maintain their transceivers tuned to the SCH. Extended and immediate modes are not appropriate for vehicles that are interested both in safety and no safety services. Subsequently, in this paper we only focus on the alternating access scheme.

B. The WAVE channel allocation scheme

During the CCH Interval (CCHI), static and mobile nodes wishing to offer or use an infotainment service should tune their radio to the CCH. While providers announce the availability of their services broadcasting WAVE Service Advertisements (WSAs), users can listen to these advertisements, sent by the neighboring nodes. The WSA message, whose format is illustrated in Figure 2, indicates service information and the advertising channel. Indeed, services are identified in the WSA via the Provider Service Identifier (PSID) value specified in the Service Info field. The PSID is unique for every application area. Since the application area could be general, the Provider Service Context (PSC) may be added into the EXT field to determine if the application service is of interest of the user application. Upon reception of WSA messages, each node can update a local table about the availability of the SCHs. According to the IEEE1609.4 std. the table is very simple, and does not keep any information about which provider is using the SCH, and for how long it will keep it busy.

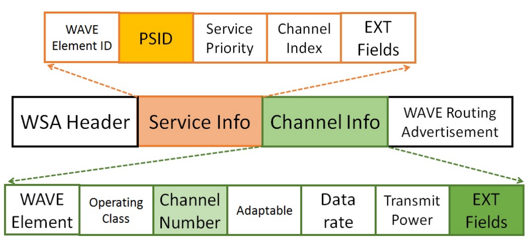


Fig. 2. WSA message format

III. Proposed Approach

In this section, we explore how the Software Defined Network (SDN) paradigm can be leveraged to efficiently overcome the limitations of current channel allocation strategy in VANETs. Subsequently, we describe ESCiVA, a service channels allocation scheme for IEEE802.11p/WAVE based VANETs, orchestrated by SDN controllers implemented in the infrastructure.

A. Architecture

SDN decouples the data forwarding plane from the control plane logic. By centralizing network control, and by providing a dynamic, flexible, and automated reconfiguration of the network, SDN has gained increasing interest not only in wired, but also wireless and mobile networks. Such interest in SDN has raised the stakes on developing new architectures also for VANETs. A pioneer work on SDN-enabled VANETs was proposed by Gerla et al in [10]. They defined an architecture that supports different operating modes: centralized, distributed and hybrid control mode. Since potential communication losses and high mobility are inherent issues in VANETs, the hybrid mode is the most suitable control mode. This pioneer architecture was enhanced in [12] and in [13] by adding cloud and fog components. Our architecture, illustrated in Figure 3, is in line with the one proposed in [10], but unlike that one, SPs can be both static (i.e., RSUs) and mobile nodes (i.e., moving vehicles).

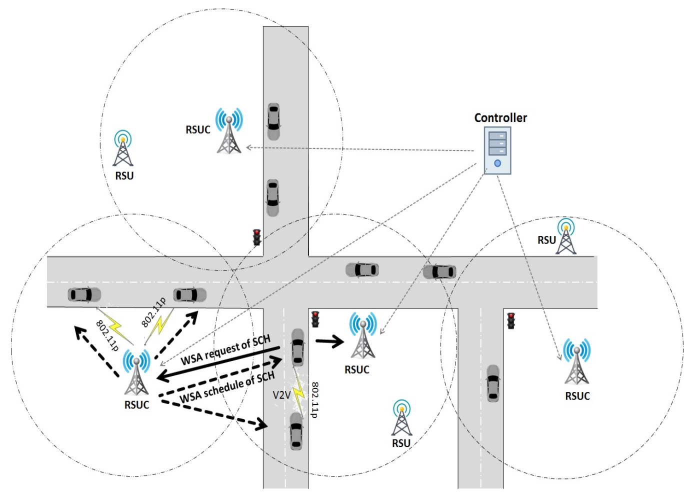


Fig. 3. Proposed SDN-enabled VANET Architecture.

The main components of the proposed SDN-based architecture for IEEE802.11p/WAVE-enabled VANETs are:

- *The RSU Controller (RSUC)*: it is an RSU enabled with SDN logic. It is aware of network topology, density, and mobility pattern of vehicles, thanks to the information received in the beacons sent periodically by all the mobile nodes in the network. The RSUC is in charge to collect the requests of providers (RSUs and vehicles) in its coverage range, and to build the schedule, using the ESCiVA approach. While mobile nodes mainly communicate using IEEE802.11p/WAVE standard, RSUs can also be connected to RSUCs through broadband connections (LTE, 5G, etc). All distributed RSUCs are orchestrated by a central SDN controller, responsible for coordination and interference's management inter-RSUCs.
- *RSUs*: each RSU is managing a cluster of vehicles via V2I communications. To acquire the channel for a given service (either provided by the RSU itself or by a vehicle outside the coverage range of the RSUC), the RSU will exchange WSAs with the RSUC.
- *Vehicles*: can act as end-users or providers for a given service. These mobile SPs are controllable by the RSUC and/or the RSUs in their coverage range via V2I communications. In case a vehicle is a SP, it will exchange WSA messages with the RSUC to ask for a SCH, and receive the assigned schedule. If no RSUC is in the coverage range of the vehicle, then the WSAs (request/response) will be forwarded by a RSU to the RSUC.

The proposed architecture ensures channel allocation flexibility thanks to the dynamic programming feature of SDN. Moreover, it is versatile: in fact, besides the designed ESCiVA approach, other scheduling strategies can be implemented in the RSUCs, according to the policies that ITS authorities would like to adopt.

B. ESCiVA: An Efficient Service Channel Allocation Scheme

According to the IEEE802.11p/WAVE standard, each provider willing to offer a service, selects a SCH currently available, and announces it in the WSA messages exchanged in the CCH. Such local decision, and distributed approach do not allow to optimize the SCHs usage. Thus, we propose ESCiVA that leverages on the centralized network control offered by SDN to efficiently allocate the six SCHs to service providers, taking into account current channel availability, and past history of the SCHs utilization, potential interference among adjacent SCHs, and mobility of the providers. ESCiVA aims to achieve a fair usage of all the SCHs, balancing the traffic load offered to them, and to reduce the interference among adjacent channels, and in the same SCH among mobile providers moving in overlapping coverage ranges. The algorithm runs on the RSUCs that using the information received in beacons (about network topology, vehicle speed and direction), and WSAs (about channels and services) can allocate the SCHs in an efficient manner. In particular, each RSUC maintains a table, namely *SCH Status Table* (Table I). Unlike what simply

TABLE I
EXAMPLE OF SCH STATUS TABLE, MAINTAINED BY THE RSUC

$SCHi$	TOT_{SCHIi}	TTF_{SCHi}
172	12	6
174	15	0
176	13	8
180	12	0
182	14	0
184	15	0

defined in IEEE802.11p/WAVE std. (i.e., each node, fixed or mobile, keeps track only of the current status of the SCHs: busy/free), we propose to add two counters in the SCH Status Table. The first one, TOT_{SCHIi} represents the total assigned SCHIs over several service requests, since the deployment of the network. It ensures fair load allocation among the six SCHs, avoiding to overload few channels, while leaving others unused. The second counter is the TTF_{SCHi}, "Time To become Free". Upon request of a SCH from the provider, the RSUC sets the TTF_{SCHi} to the number of SCHI requested by the provider ($NbReqSCHI$). At each SI, the counter is decreased of 1, and when it becomes equal to zero, the status of the corresponding SCH is updated to free. An illustrative example of the SCH Status database is provided in Table I.

To enable the exchange of the SCH requests by the providers, and the SCH reservation/schedule by the RSUCs (in other words, the signaling flow, according to the SDN parlance), we propose to leverage on the IEEE802.11p/WAVE standard, and use WSA messages, by encapsulating the needed

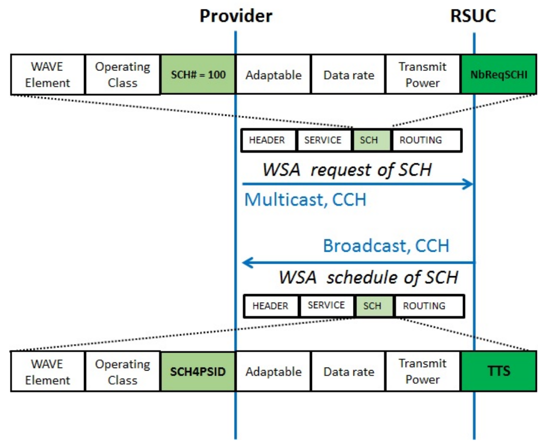


Fig. 4. WSA messages exchange between provider and RSUC to assign a SCH to a service.

information within their extension fields. Such approach makes ESCiVA feasible in already deployed networks, without the need of developing a suitable protocol for the SBI of SDN wireless mobile networks, not yet defined. Basically, two type of WSA messages are identified:

1) *WSA request of SCH*: this request is generated by the application at the provider (RSU or vehicle), and sent in multicast to the RSUCs on the CCH (see Figure 4). To get access to the WAVE service, the application should be registered with its unique Provider Service ID, PSID. The channel number in the WSA request is set to 100 to announce that no SCH has been assigned yet for that service. The provider also specifies in the EXT field for how long (in term of SCHIs, $NbReqSCHI$) it would like to broadcast the service, and thus use the SCH;
2) *WSA schedule of SCH*: upon reception of the WSA request, the RSUC selects the SCH to assign to the provider, using the ESCiVA Algorithm described hereafter. The WSA schedule is broadcasted on the CCH, and details the specific SCH allocated to that service, and the time when the provider can start offering the service on that assigned SCH (i.e., Time to Start TTS) as illustrated in Figure 4. The RSUC can summarize in the same message the schedule related to different providers requesting a SCH in the same CCHI. Being the WSA broadcasted, not only the providers get to know the SCH reserved for them, but also vehicles interested in a given service can synchronize on the SCH where it is made available.

C. ESCiVA Algorithm

The ESCiVA Algorithm, running at the RSUC, is articulated in a set of steps as described in Algorithm 1. The Algorithm takes as inputs the SCHs list, the PSID, the number of requested SCHIs and the *SCHs Status Table*. Before assigning a SCH to a provider, the RSUC verifies which SCH satisfies a set of conditions, using the information within the *SCHs Status Table*.

- *Status of the SCH:* Upon reception of the *WSA request for SCH* in the CCHI, the RSUC checks the status of the service channels. The RSU selects the SCHs that will be available in the following SCHI, i.e., those with $TTF_{SCHi} = 0$ (line 10-11). In case all the service channels are currently busy, the RSUC selects those that will be freed earliest, in maximum 10 SCHs (i.e., $0 < TTF_{SCHi} \leq 10$ SCHIs). In fact, given that providers are mobile, it is high the probability that in more than 10 SCHs they will be under the coverage range of another RSUC (line 13).

- *SCH Past usage:* In order to fairly use all the six SCHs, and avoid to overload few of them, the RSUC checks the past usage of the set of free SCHs, selecting those with smaller TOT_{SCHIi} (line 15). By doing so, it avoids to assign to the provider a channel that just became free, and it was already used a lot in the previous SIs.

- *Adjacent Channels Interference:* Once identified the free and less used SCHs, the RSUC selects those that have a lower probability of interfering with adjacent channels. To this end, it checks the value of TTF_{SCHi} of the adjacent channels for each SCH in the $LeastUsedSCHs$ List, and compute in how many SCHIs, over the requested $NbReqSCHI$, the provider may interference with another using one of channels adjacent to that SCH (line 16 to 38).

- *Future Interference due to mobility of provider:* If from the previous checks the RSUC identifies only one SCH that satisfies all the conditions, then it assigns such channel to the provider (line 39) . Either wise, the RSUC also check potential interference on the same channel due to other providers that may have been assigned the same SCH from the RSUC managing the neighbor cluster. The RSUC owns the information about channel usage in neighbor clusters, being able to communicate with other RSU controllers in overlapping coverage areas[1].

- *Time to start providing the service:* Once identified the SCH to assign to the provider (line 39), the RSUC will broadcast on the CCH the *WSA schedule of SCH* message where it also specifies the *Time to Start* (TTS) the service. If the selected SCH is available from the next SCHI, then the provider can start as soon as the CCHI is over. Either wise it will wait till the SCH is made free (i.e., the TTF_{SCHi} becomes equal to zero) (line 40).

[1]Note this last check of inter-cluster interferences has not been highlighted in the pseudo-code due to the increased complexity that it implied in the notation.

Algorithm 1 ESCiVA Pseudocode

1: **Input:** $SCHsList$; $PSID$; $NbReqSCHI$, $SCHstatusTable$
2: **Output1:** $SCH4PSID$ /* SCH assigned to service $PSID$ */
3: **Output2:** TTS /*Time To Start the service $PSID$ on SCH */
4: **Initialization**
5: $SCHsList \leftarrow SCHi, 1 \leq i \leq 6$ /*List of SCHs*/
6: $FreeSCHsList \leftarrow null$ /*List of current free SCHs*/
7: $LeastUsedSCHs \leftarrow null$ /*List of current least used SCHs*/
8: $LeastAdjInterfSCHs \leftarrow null$ /*List of SCHs suffering from the smallest level of adjacent interferences*/
9: **ESCiVA operating mode at the RSUC**
10: **if** $\exists\ SCHi \ni' TTF_{SCHi} = 0$ **then**
11: $FreeSCHsList(SCHsList) \leftarrow SCHi$ with $TTF_{SCHi} = 0$
12: **else**
13: $FreeSCHsList(SCHsList) \leftarrow SCHi$ with $TTF_{SCHi} \leq 10$.
14: **end if**
15: $LeastUsedSCHs(FreeSCHsList) \leftarrow$ sort($FreeSCHsList$) by incremental TOT_{SCHIi}.
16: $AdjInterfList(size) \leftarrow$ size ($LeastUsedSCHs$)
17: Initialize $AdjInterfList$
18: $k \leftarrow 1$
19: **repeat**
20: $sch \leftarrow LeastUsedSCHs[k]$
21: $levelInterf \leftarrow 0$
22: **if** $TTF_{SCH(sch-1)} \geq NbReqSCHI$ **then**
23: $levelInterf \leftarrow levelInterf + NbReqSCHI$
24: **else**
25: **if** $0 \leq TTF_{SCH(sch-1)} \leq NbReqSCHI$ **then**
26: $levelInterf \leftarrow levelInterf + TTF_{SCH(sch-1)}$
27: **end if**
28: **end if**
29: **if** $TTF_{SCH(sch+1)} \geq NbReqSCHI$ **then**
30: $levelInterf \leftarrow levelInterf + NbReqSCHI$
31: **else**
32: **if** $0 \leq TTF_{SCH(sch+1)} \leq NbReqSCHI$ **then**
33: $levelInterf \leftarrow levelInterf + TTF_{SCH(sch+1)}$
34: **end if**
35: **end if**
36: $AdjInterfList(k) \leftarrow levelInterf$
37: $k \leftarrow$ ++
38: **until** $k > size(LeastUsedSCHs)$
39: $SCH4PSID \leftarrow LeastUsedSCHs(index(MIN(AdjInterfList))$
40: $TTS \leftarrow TTF_{SCH4PSID}$

IV. Performances evaluation

Conducted studies [9] have demonstrated that in scenarios where the transmission range of vehicles are large (around 1Km) and vehicle density is high, SCHs become drastically saturated and thus throughput-sensitive services are hampered. Consequently, a fundamental challenge in VANETs is the efficient allocation of SCHs to make sure all the channels are equally used and loaded, and to avoid possible interference intra- and inter-channels. We position ESCiVA in this challenging scenario. In this section, we first describe the tools used for simulating an SDN-enabled VANET implementing ESCiVA. Then, we evaluate the performance of ESCiVA against the IEEE802.11p/WAVE standard approach, in term of fair usage of all the SCHs, and probability of collision on the same SCH, expressed as percentage of SCH at risk.

A. Simulation settings

Simulations have been conducted using Veins framework which integrates the network (OMNET++) and the traffic mobility simulator (SUMO) by establishing a TCP connection between them. Veins is specifically designed for VANETs and supports the IEEE802.11p standard. To evaluate the performance of ESCiVA, we have simulated the scenario illustrated in Figure 5, consisting in an urban grid map, with road segments of length 745 and 725 meters, respectively. Two RSUCs are managing the urban area by orchestrating

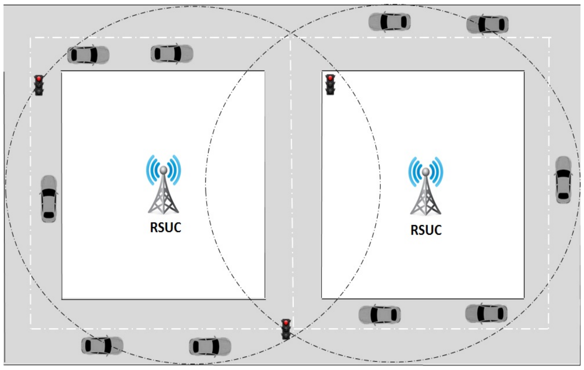


Fig. 5. Simulated scenario.

vehicles transmissions, and they can hear each other (i.e., their coverage range is overlapping). In our scenario, we assume sixty vehicles are moving: few of them are selected as mobile providers to provide service applications. Each of them move following a random path, among three that have been initially identified in the scenario. The remaining vehicles act as users which may be interested or not in the services made available by the providers. Vehicle speed has been set randomly, in the range [80, 130] km/h. For simulation purpose, the standard alternate mode with six SCHs is considered and hence CCHI and SCHI are equal to 50 ms. The simulation is run for 150 sec so moving vehicles can enter one of the RSUC transmission range, go through the overlapping area of the two RSUCs and finally leave it.

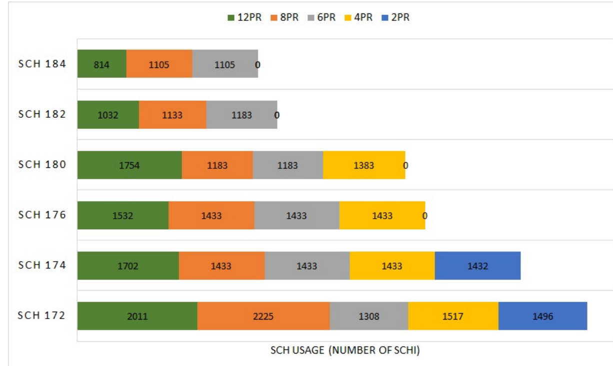
Table II summarizes the main simulation parameters, and their respective value.

TABLE II
SIMULATION PARAMETERS

Parameter	Values
Number of Vehicle	60
Number of Providers	$\in \{2, 4, 6, 8, 12\}$
Average speed of vehicles	$\in$ [80, 130]Km/h
Vehicle communication range	1 Km
RSUC communication range	1 Km
Grid size	745x725 m
$NbReqSCHI$	$\in [1, 5]$
$SCHI$ and $CCHI$ duration	50 ms (each)
Simulation Time	150 sec

B. Result Analysis

In this section, we present the performance of ESCiVA evaluated in term of SCHs occupancy level and overlapped transmissions ratio, on the same SCH, namely SCHs at risk.



(a) WAVE standard scheme

(b) ESCiVA scheme

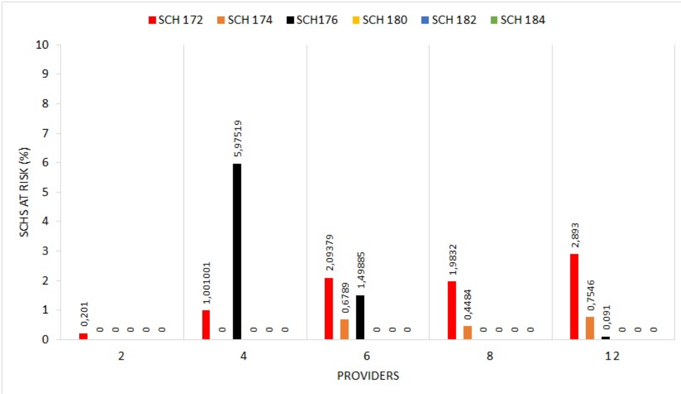
Fig. 6. SCHs occupancy level

1) SCH occupancy level: Figure 6 shows SCHs occupancy level vs. number of providers when implementing the standard WAVE scheme and ESCiVA.

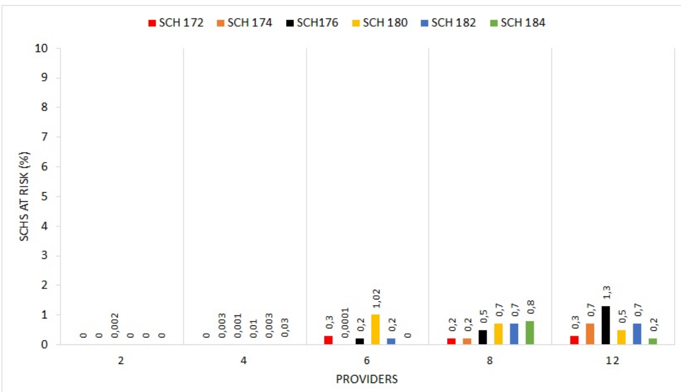
Figure 6(a) shows that under the WAVE legacy scheme, where the first free available SCH is selected, few SCH are highly loaded specifically when the number of providers is less than 6. Some SCHs are never used. When the number of provider gets larger (≥ 6), the channel load difference between SCHs gets smaller. However, as depicted in Figure 6(b), for ESCiVA SCHs are fairly used in all cases even when the number of providers is less than 6. This shows the merit of ESCiVA in balancing the traffic among the available SCHs. Subsequently, collisions are enormously avoided.

2) SCHs at Risk: Due to mobility, some scheduled providers on specific channels can cause conflicts while they are serving users. To evaluate this conflict, we adopt the concept of SCHs at risk from [8]. The SCHs at risk is defined as the percentage of SCHIs in which two (or more) providers with overlapping radio coverage initialize services on the same service channel. Subsequently, this metric assesses the capability of the compared schemes to cope with frequency overlapping of nearby providers.

Figure 7(b) shows that ESCiVA exhibits a lower SCHs at risk ratio than the WAVE standard. Even when the number of providers is high (more than 6), ESCiVA shows clear improvements compared to the standard scheme. For 12 providers, ESCiVA presents 1.3% of risk while the standard scheme



(a) WAVE standard scheme



(b) ESCiVA scheme

Fig. 7. SCHs at risk

suffers from 2.9% of risk. Hence, using ESCiVA scheme over the static WAVE legacy scheme, ensures no conflict on the SCHs and thus guarantees significant improvement in the throughput.

V. Conclusion

In this paper, An Efficient Service Channel Allocation Scheme for SDN-enabled VAnets (ESCiVA) is proposed to balance service channels occupancy among multiple providers offering different services. The emerging SDN paradigm, implemented in the infrastructure, is leveraged to efficiently overcome the limitation of the current channel allocation scheme in IEEE802.11/WAVE standard. WSA messages are enriched with additional fields that enable the SDN controller at the RSU to orchestrate channel scheduling. To show the feasibility of ESCiVA, simulations are conducted using Veins. The SCHs occupancy is evaluated extensively under different numbers of providers. Moreover, the risk of scheduling two conflicting providers is studied. As a result, the proposed ESCiVA enhances the load balance among the SCHs and drastically decreases the SCHs at risk. As a future work, we plan to further improve the algorithm by distinguishing primary from secondary providers delivering respectively safety-related and infotainment information.

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