<http://www.diva-portal.org>

Postprint

This is the accepted version of a paper presented at *1st IEEE ICC Workshop on Dependable Vehicular Communications (DVC 2015), London, United Kingdom, June 12, 2015.*

Citation for the original published paper:

Campolo, C., Molinaro, A., Vinel, A., Lyamin, N., Jonsson, M. (2015)
Service Discovery and Access in Vehicle-to-Roadside Multi-Channel VANETs.
In: *2015 IEEE International Conference on Communication Workshop* (pp. 2477-2482).
Piscataway, NJ: IEEE Press
<http://dx.doi.org/10.1109/ICCW.2015.7247548>

N.B. When citing this work, cite the original published paper.

Permanent link to this version:

<http://urn.kb.se/resolve?urn=urn:nbn:se:hh:diva-29201>

Service Discovery and Access in Vehicle-to-Roadside Multi-Channel VANETs

Claudia Campolo*, Antonella Molinaro*, Alexey Vinel[†], Nikita Lyamin[†], and Magnus Jonsson[†]

*Università Mediterranea di Reggio Calabria, Italy. E-mail: name.surname@unirc.it

[†]Halmstad University, Sweden. E-mail: name.surname@hh.se

Abstract—A wide portfolio of safety and non-safety services will be provided to drivers and passengers on top of Vehicular Ad Hoc Networks (VANETs).

Non-safety services are announced by providers, e.g., road-side units (RSUs), on a channel that is different from the one where the services are delivered. The dependable and timely delivery of the advertisement messages is crucial for vehicles to promptly discover and access the announced services in challenging vehicle-to-roadside scenarios, characterized by intermittent and short-lived connectivity.

In this paper, we present an analytical framework that models the service advertisement and access mechanisms in multi-channel vehicular networks.

The model accounts for dual-radio devices, and computes the mean service discovery time and the service channel utilization by considering the disruption periods due to the switching of the RSU from the advertising channel (where announcements are transmitted) to the advertised channel (where services are exchanged), under different channel and mobility conditions. It provides quick insights on parameter settings to allow providers to improve service provisioning.

Index Terms—VANET, Multi-Channel, Service Advertisement.

I. INTRODUCTION

After more than a decade of research efforts, Vehicular Ad Hoc Networks (VANETs) are close to become a reality, as confirmed by worldwide initiatives aimed to bring short-range wireless communication technologies into newly sold vehicles.

VANETs are expected to provide a rich menu of applications ranging from safety-critical messages delivery to traffic efficiency and comfort/convenience services. Indeed, enhancing road-safety has always been the matter of primary concern in a VANET. However, interest has surged in non-safety services as enablers of market penetration for connected vehicles. For instance, traffic information, parking lots availability and points-of-interest notifications can be provided to vehicles, or data collected from on-board and on-the-road environmental sensors can be uploaded by vehicles to a remote center.

Typically, non-safety services are offered by road side units (RSUs) deployed along the road and acting as *providers*. Passing by vehicles can discover and locally consume the services they are interested in, by leveraging vehicle-to-roadside (V2R) communications. Due to high deployment costs sparse roadside infrastructure will be initially provided, that coupled with the high mobility of vehicles would result in intermittent and short-lived V2R connectivity.

Unlike traditional Wi-Fi based networks, multiple channels are available in the allocated spectrum for vehicular communications [1], to be *simultaneously* used by safety and non-safety services, so (i) to mitigate congestion under high traffic load conditions and (ii) to better fit the heterogeneous service requirements, with special attention devoted to the strict demands of safety-critical traffic. When dual radio transceivers are used in RSUs and on board the vehicles, typically one of the radio is continuously tuned onto a channel dedicated to safety services, while the other one is used for the announcement and delivery of non-safety services. We will refer to this (non safety) radio transceiver hereinafter.

There is no traditional beaconing in VANETs, instead, the RSU *regularly* announces the available services on a known channel (hereinafter, the *advertising channel*). The announcements carry the provider and service information, timing and network configuration parameters (e.g., default gateway address), and the channel frequency where the service can be accessed.

Once alerted, an interested vehicle simply tunes its transceiver to the announced frequency (hereinafter, the *advertised channel*) and accesses the offered service(s) until it is under the coverage of the RSU.

According to the latest standard specifications by ETSI [2] and IEEE [3], *the advertising channel is different from the advertised channel*. The advertising channel is used like a rendez-vous channel, *i.e.*, the same for all. Indeed, it cannot sustain all possible vehicular services [4], so different services may be provided on different advertised channels. Therefore, a provider that intends to announce and offer its services has to *switch its non-safety radio transceiver between the two channels*, alternating between service announcements and service provisioning procedures. Providers and users should meet on the advertising channel so that services can be discovered and subsequently consumed.

The standards do not give any specific indication about the regularity of the service announcement; however, it has an effect on the system performance. Indeed, short-latency and dependability are among the main requirements of the announcement procedures to allow vehicles to become *timely* aware of the available services and make the most of the short time they stay connected to the RSU.

On the one hand, the more frequently a service is announced the shorter the *service discovery time* (*i.e.*, the time necessary to detect a service announcement on the advertising channel) will be and the higher the *service discovery probability*,

(i.e., the probability to detect the presence of a nearby provider when under its coverage).

On the other hand, any time a provider announces a service it needs to switch back to the advertising channel and creates a *service disruption* period on the advertised channel due to its absence. The more frequently an announcement is transmitted, the longer the service disruption will be, with a negative impact on the *advertised service channel utilization* and the quality of service experienced by served vehicles.

The objective of this study is to understand the above-mentioned trade-off and give an insight into the performance of service advertisement and access procedures in multi-channel VANETs.

The major contribution is the conceived analytical framework that relates the *service announcement period*, i.e., the time interval between successive periodic announcements with the *service discovery time*, and the *advertised service channel utilization*.

The analysis serves the purpose to provide quick insights into the service announcement period settings to service providers by considering the effects of channel load conditions and kinematics parameters. The latter ones are captured by the residence time, in turn affected by the vehicle speed and the communication range.

The rest of the paper is organized as follows: Section II describes multi-channel operations in VANETs along with service advertisement procedures; Section III presents the proposed analytical framework; Section IV reports evaluation results, and Section V concludes the paper.

II. MULTI-CHANNEL VANETs

Spectrum Allocation. A milestone for the VANETs deployment was the allocation of a reserved bandwidth to Intelligent Transportation System (ITS) radio services in the 5 GHz spectrum worldwide, Figure 1.

One Control Channel (CCH) and multiple Service Channels (SCHs) are assigned for the provisioning of safety and non-safety vehicular services [1].

In US, taking into account the Federal Communication Commission recommendations and the recent decisions of the automotive industries [1], the service channel CH 172 has been designated for exclusive use of public safety, including vehicle-to-vehicle collision avoidance and mitigation. In Europe, instead, safety messages are transmitted on the CCH [2].

Regarding non-safety services, service providers announce the offered service(s) by transmitting a service advertisement message indicating the service characteristics and on which channel it can be accessed. Vehicles tune their transceiver to the indicated channel to consume the service.

Service Announcement Message (SAM) is the term used in ETSI documents [2]; in the IEEE Wireless Access in Vehicular Environment (WAVE) WAVE Service Advertisement (WSA) is instead used [3].

Service advertisements are broadcasted on the CCH for IEEE [3], while for ETSI [2] the announcements should take place on SCH1 (or SCH3) unless the CCH is in “relaxed” state (i.e., not crowded), in which case the transmission may take place on the CCH.

TABLE I
CHANNEL ALLOCATION IN US AND EUROPE FOR DUAL-RADIO DEVICES

Region	Safety channel	Advertising channel	Advertised channel
US	CH 172	CCH	Any SCH (except CH 172)
Europe	CCH	SCH1 (or SCH3)	SCH2-SCH4

Previous studies [5] demonstrated that the CCH is typically in a congested state due to periodic messages from a large number of vehicles (i.e., beacons) and from RSUs (e.g., Signal Phase and Time, SPaT, messages), and to *event-triggered* safety messages [2]. So, it would be highly likely that in Europe service announcements take place on SCH1 or SCH3, according to the type of ITS station, instead of CCH.

Vehicles offering services may piggyback service information in their transmitted beacons on the CCH instead. In this way, switching the second transceiver is avoided and services can be exchanged without any disruption.

The advertised channel, where non-safety services are offered, can be any SCH except CH 172 in US, while in Europe it can be SCH2-SCH4, if announcements are transmitted on SCH1, or SCH4 if they are transmitted on SCH3 [2].

In summary, in both US and Europe, it would be highly likely that *the service advertising channel is different from the advertised channel and safety messages are transmitted on a dedicated channel*, so they do not interfere with service announcements and delivery.

Dual-Radio Devices and Multi-Channel Operations. Vehicular devices with dual-radio transceivers, capable of simultaneous operation on two radio channels, are considered the most accredited configuration to support simultaneously safety and non-safety services [1]¹. Not only vehicles, but also RSUs need to monitor the safety channel and take part to safety data exchange, e.g., to relay received information about road accidents and hazards, to warn vehicles approaching a blind area (e.g., a road intersection/merge), etc. Given the above considerations and following Table I, it would be expected that in each dual-radio device: (i) one radio is constantly tuned to the safety channel and (ii) the second radio switches between the *advertising channel*, where service announcements are transmitted, and the *advertised channel*, where services are provided and consumed.

A *synchronous switching* is assumed in WAVE [10]. Nodes are synchronized to the UTC (Coordinated Universal Time) and the channel time is divided into synchronization intervals with a fixed length of 100 ms, consisting of a CCH interval and a SCH interval (typically 50ms-long), where the radio transceiver is respectively tuned into the CCH and one of the (advertised) SCHs. The advertisement messages on the CCH [3] can be repeated several times over a given time period. Specifically, the *Repeat Rate* field in the WSA message indicates the number of times it will be transmitted in a 5s reference interval. This number can be tuned by the provider

¹RSUs may be equipped with more than two radios to improve service provisioning. However, the simultaneous operation of multiple radios tuned into nearby channels on the same node imposes further challenges due to the adjacent channel interference [9].

based on the priority and the time-relevance of the advertised service (e.g., weather alert, points-of-interest notification, parking lots availability). However, no rules are specified in the 1609.3 standard for its settings.

Mechanisms about the repetition of service announcements and the switching dynamics are still not defined in ETSI.

However, it is likely that an *asynchronous* switching will be considered between the advertising and the advertised channel [2], [4].

Fig. 1. Spectrum allocation in USA (top) and Europe (bottom).

Main issues. When dealing with non-safety traffic in multi-channel VANETs, the main challenge is the mentioned fact that service advertising and access take place on different channels; this makes the prompt and robust reception of service parameters a concern particularly in fast-moving and dense environments. The packet failures due to congestion and channel errors on the advertising channel could lengthen the service discovery time, which on its turn critically affects the residual connectivity time available between the vehicles and the serving provider. Collisions may occur between SAMs and other types of messages. In US, they could be non-IP messages such as WAVE Short Messages [1]. In Europe, they can be non-safety data or offloaded traffic from CCH (e.g., for multi-hopping).

Non-safety service discovery and access when considering multi-channel operations is a rather unexplored area.

In some preliminary works [6] and [7] the authors proposed to increase service awareness in the RSU neighbourhood by piggybacking service information in periodic beacons generated by each vehicle. In [4] a *fully asynchronous* multi-channel switching mechanism is devised that aims to maximize the SCH usage. Nodes periodically return to the advertising channel (every T_{duty}) and stay tuned on that channel for a period (T_{SCH1}) whose duration is longer than 200 ms. T_{SCH1} is uniformly spread during T_{duty} to improve the rendez-vous probability of service providers and service consumers.

Like the work in [4] we assume that service providers periodically switch between the advertising and the advertised channel. However, in contrast to it, the provider stays tuned into the advertised channel only for the time needed to send a SAM. Such a choice is motivated by the need to reduce the disruption for services delivered on the advertised channel, when the RSU switches to the advertising channel.

III. ANALYTICAL FRAMEWORK

A. Main Assumptions and Notations

Our analysis focuses on a vehicle-to-roadside scenario with vehicles approaching the coverage area of an RSU that acts as a provider and offers a given (set of) service(s). The residence time of a vehicle, i.e., the time a vehicle spends under the RSU coverage, is denoted as T . This time is a function of the vehicle density/speed and road type, the transmission power, the receiver sensitivity and the propagation environment.

Both vehicles and RSU have *dual radio transceivers* configured as described in Table I and we focus on the *behaviour of the second switching radio interface*.

Specifically, the RSU regularly, at every τ , referred to as the *SAM period*, switches the second transceiver between the advertising and the advertised channel.

Once tuned into the advertising channel, the RSU attempts to seize the channel to transmit a SAM².

During this time, we denote as x and representing the *mean service disruption time* on the advertised channel at every SAM period, the RSU cannot provide services to passing by vehicles. It is computed as illustrated in Figure 2 and accounts for the switching times from the advertising channel to the advertised channel (T_{sw}) and vice versa and for the time needed to transmit a SAM. The latter contribution is affected by the experienced channel load condition, i.e., the number of potential interferers attempting to transmit a packet.

A SAM may fail with probability p , due to channel impairments and collisions with other packets on the advertising channel.

Before entering the RSU's coverage, each vehicle has the second transceiver tuned into the advertising channel to detect the presence of nearby providers advertising locally available services. Once it enters the RSU coverage and successfully receives the SAM, it switches to the advertised channel to consume the service(s) it is interested in.

The analytical expressions for p and x are presented in the following subsections.

Under the described settings and assumptions, the model aims at computing the following performance metrics:

- the *mean service discovery time* $D(\tau)$, defined as the expected time that elapses from the moment a vehicle enters the RSU coverage until the moment it successfully receives the SAM³;
- the *service channel utilization* $U(\tau)$, which represents the fraction of the residence time T available for accessing the service; it starts from the successful SAM reception and ends when the vehicle goes out of the RSU's radio range, also excluding service disruption times.

B. SAM failure probability

When the target RSU attempts transmitting a SAM packet on the advertising channel, it might find interfering nodes contending for seizing the channel to transmit packets.

²For the sake of simplicity, we will refer to advertisements as SAM.

³ $D(\tau)$ is defined only if a vehicle manages to discover the service during the residence time.

Fig. 2. SAM delivery and main parameters (SCH1 is the advertising channel) as observed by a vehicle during its permanence (T) under the RSU's coverage

Without loss of generality and for the sake of simplicity we consider homogeneous interfering *broadcast* traffic on the advertising channel. The same analysis could be applied when considering unicast traffic, by properly changing the collision probability. The number of interfering nodes is set to N^4 .

Applying the well-known approach to approximate the backoff procedure with contention window W by the sequence of independent transmissions with probabilities $2/(W+1)$ (see [8]), the SAM collision probability p_0 can be derived as follows:

$$p_0 = 1 - \left(1 - \frac{2}{W+1}\right)^N, \quad (1)$$

where W is the contention window size. Therefore, the SAM failure probability p due to collisions or independent channel-induced bit errors, can be computed as:

$$p = 1 - (1 - BER)^L(1 - p_0), \quad (2)$$

with L being the SAM packet size and BER the bit error rate.

C. Mean service disruption

At every τ the RSU leaves the advertised channel, where it offers services, for a time equal to x , needed to switch to the advertising channel and back to the advertised channel and to transmit the SAM.

Interfering packets on the advertising channel might influence the backoff delay $B(w)$ of the target RSU attempting to transmit a SAM, which can be modeled via the following recursive equation:

$$B(w) = 1/w \cdot 0 + (1 - 1/w) \cdot \{(1 - p_0)[\sigma + B(w - 1)] + p_0[x_0 + B(w - 1)]\}, \quad (3)$$

where $x_0 = T_h + L/R + SIFS + AIFSN \cdot \sigma$ is the time to transmit the SAM including the mandatory idle time on the channel, with values given in Table II.

⁴Future efforts will be devoted to analytically determine N .

The first contribution in (3) accounts for the transmission of the target RSU: it transmits in the current slot with probability $1/w$. The second one, multiplied by the probability that no transmission occurs for the target node $(1 - 1/w)$, accounts for backoff decrement if no nodes transmit and for the transmission of an interfering packet which causes the backoff freezing for the entire transmission x_0 .

Finally, the mean service disruption time can be derived as follows:

$$x = B(W) + x_0 + 2T_{sw}. \quad (4)$$

D. Mean service discovery time

Proposition 1. The mean service discovery time $D(\tau)$ is:

$$D(\tau) = \tau \cdot \frac{np^{n+1} - np^n - p^n + 1}{(1-p)(1-p^n)} + (x - \tau) \quad (5)$$

Proof: A vehicle enters the RSU coverage and waits for a random number of SAM periods $1 \leq i \leq n$ before successfully receiving a SAM, which is broadcasted every τ seconds⁵. Since a SAM fails with probability p , the probability that the SAM is successfully received at the i -th attempt is $p^{i-1}(1-p)$. Then, by assuming that a SAM takes a time x to be delivered at the i -th successful attempt, we obtain:

$$D(\tau) = \sum_{i=1}^n \frac{p^{i-1}(1-p)}{1-p^n} \cdot \{(i-1)\tau + x\}. \quad (6)$$

The denominator $(1-p^n)$ (hereafter, P_{disc}) represents the *service discovery probability*, i.e., the condition that the service discovery occurs (p^n is the probability that the vehicle is not able to receive any SAM during the residence time T).

We apply a traditional technique to simplify Eq. (6) by representing it as a first derivative of a truncated geometric series sum, what leads to Eq. (5). ■

⁵We assume for simplicity of presentation that a vehicle enters the RSU coverage exactly at the beginning of a SAM period. If it is not the case, $\frac{\tau}{2}$ should be added.

TABLE II
INPUT PARAMETERS

Parameter	Value
Slot time (σ)	13 μ s [11]
Contention window size (W)	15 [11]
Short Inter-Frame Space ($SIFS$)	32 μ s [11]
Arbitration Inter-Frame Space Number ($AIFSN$)	6 [11]
Interfering packets on the advertising channel (N)	0, 5, 10, 15
SAM payload size (L)	≈ 300 bytes [3]
SAM header duration (T_h)	40 μ s [11]
SAM data rate (R)	6 Mbps [11]
SAM transmission time (including overhead) (x_0)	≈ 550 μ s
SAM bit error rate (BER)	10^{-4}
SAM collision probability (p_0)	$f(W, N)$
SAM failure probability (p)	$f(BER, p_0)$
SAM period (τ)	variable in 0.1s-1s
Residence time (T)	10, 20 s
SAM periods during T (n)	$f(T, \tau)$
Channel switching delay (T_{sw})	4 ms [10]
Mean service disruption time (x)	$f(T_{sw}, x_0, p_0)$

E. Service channel utilization

Proposition 2. The service channel utilization $U(\tau)$ is:

$$U(\tau) = \frac{x - \tau}{T} \cdot \frac{(np^{n+1} - np^n - p^n + 1)}{1 - p} + \frac{T - xn - x + \tau}{T} \cdot (1 - p^n) \quad (7)$$

Proof: The useful time for service access on the advertised channel is the residual part of the residence time T after the SAM has been received. It must be deprived of the time spent by the RSU in regular switching to the advertising channel for SAM transmissions. Applying the same reasoning as in Proposition 1, we multiply the service discovery probability in the i -th SAM period and the respective discovery delay $(i - 1)\tau$ as well as $(n - i + 1)$ switching events. Thus, the service channel utilization can be expressed as:

$$U(\tau) = \sum_{i=1}^n p^{i-1}(1 - p) \cdot \left\{ 1 - \frac{(i - 1)\tau + (n - i + 1)x}{T} \right\}, \quad (8)$$

what leads to Eq. (7). ■

IV. PERFORMANCE EVALUATION

The model has been implemented in Matlab with the input parameters taken from standard documents or following practical considerations, as listed in Table II⁶.

For example, the selected values of T in the order of 10-20s are common settings for a urban environment where vehicles move around 15-20 m/s and the coverage radius is up to 100-150 m, and also for a highway where the vehicle's speed increases to 35-40 m/s and the transmission range is around 200-350 m.

⁶The model has been preliminary validated through simulations that confirm the accuracy of the model; the comparative results are not shown in this paper to reduce cluttering in the plots.

Figure 3 shows $U(\tau)$, $D(\tau)$, and P_{disc} , when varying the SAM period τ and for different T and N values. As intuitively expected, the channel utilization decreases when N increases for any value of T , due to an increase of the disruption time x necessary to successfully transmit a SAM. Clearly, $U(\tau)$ decreases with T since the residual connectivity time under the RSU coverage after the service discovery is shorter. Furthermore, for any given residence time duration T , the value of τ that gives the best channel utilization decreases when N increases (e.g., for $N=0$ the optimal τ is around 500ms, whereas for $N=15$ it shrinks to around 200ms). This means that with a higher number of potential interfering nodes on the advertising channel, the provider should send a SAM more frequently to cope with the increase in the collision probability. For increasing N values, the beneficial effect of a longer T on the channel utilization is more visible. Specifically, when $N=0$ the effect of T is almost negligible since the switching time T_{sw} has a dominant effect on the service disruption duration. When N increases, a longer T helps to cope with longer disruption times due to congestion on the advertising channel.

Regarding the service discovery time, as intuitively expected, it decreases when τ is shorter, for any simulated value of T and N . Furthermore, it also increases with N because of a longer x due to a higher number of contending sources. For a given N value, the discovery time increases with T . This seemingly contradicting trend is due to the fact that the delay is computed only in case the vehicle manages to discover the service during T . Again, when N is zero, the results are not affected by T because at such a low load any SAM transmission is successful regardless of the sojourn time duration. For higher N values, the discovery probability decreases due to congestion on the advertised channel, and it may occur that no SAM is received by the vehicle during T . For instance, for $N=10$, P_{disc} is around 0.97 for $\tau=600ms$ when $T=10s$, while for $T=20s$ failures are less likely ($P_{disc} \approx 1$). This explains the divergence of curves $T=10$ and $T=20$ for a given $N > 0$.

Finally, given a certain combination of N and T , an optimal τ can be found that trades off discovery delay and channel utilization. While the discovery delay always gets beneficial effects from smaller τ values, the channel utilization can be initially penalized by a short SAM period because of more frequent service disruption intervals (this is the case, for example, of the curves with $N=10$); then it increases with τ up to an optimal value that represents the best trade off (it is around 200ms for $N=10$), and finally decreases when the SAM period gets longer because of a shorter connectivity lifetime after service discovery.

V. CONCLUSION

This paper gives a preliminary insight into service announcement and access procedures in multi-channel VANETs.

The proposed model helps to recommend the service announcement period setting. It can be used to get quick insights by playing with parameters characterizing channel conditions (the number of interferers, the BER) and mobility conditions (the residence time).

(a) Service channel utilization, $U(\tau)$

(b) Service discovery time, $D(\tau)$

(c) Service discovery probability, P_{disc}

Fig. 3. Metrics vs. the SAM period τ , for different N and T values

Results show a trade-off between service disruption and timely discovery.

Providers are recommended to set the SAM period also according to the nature of the delivered service. SAM periods that privilege higher channel utilization are particularly indicated when the provider and the vehicle should exchange a large amount of data, and/or when the serving channel is expected to be congested.

On the other hand, τ values that provide shorter discovery

time may be required when offering low-latency services and/or when a small amount of data is to be exchanged.

As a future study, we plan to analyze the trade-off arising from the willingness of a provider to increase the number of potential service consumers, *e.g.*, by enlarging its coverage range, and the quality of experience of connected vehicles, which may be adversely affected by congestion on the advertised channel.

VI. ACKNOWLEDGMENTS

The work has been partly supported by the Knowledge Foundation, Sweden in the framework of the project “ACDC - Autonomous Cooperative Driving: Communications Issues”, COST Action IC0906 “Wireless Networking for moving Objects”, and NFITS - National ITS Postgraduate School, Sweden.

REFERENCES

- [1] C. Campolo, A. Molinaro, “Multichannel Communications in Vehicular Ad Hoc Networks: A Survey”, *IEEE Communications Magazine*, 51(5), pp. 158–169, 2013.
- [2] ETSI TS 102 724 V1.1.1, “Intelligent Transport Systems; Harmonized Channel Specifications for Intelligent Transport Systems operating in the 5GHz frequency band, Channel Specifications 5 GHz,” Oct. 2012.
- [3] “IEEE 1609.3-2010, IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Networking Services,” Dec. 2010.
- [4] L. De Martini and J. Haerri, “Short Paper: Design and Evaluation of a Multi-Channel Mechanism for Vehicular Service Management at 5.9GHz”, *IEEE Vehicular Networking Conference (VNC)*, December 2013, pp. 178–181.
- [5] A. Autolitano, C. Campolo, A. Molinaro, R. Scopigno, A. Vesco, “An Insight into Decentralized Congestion Control Techniques for VANETs from ETSI TS 102 687 V1.1.1”, *IEEE Wireless Days Conf.*, pp. 1–6, November 2013.
- [6] C. Campolo, H.A. Cozzetti, A. Molinaro, R. Scopigno, “Augmenting Vehicle-to-Roadside Connectivity in Multi-channel Vehicular Ad Hoc Networks”, *Journal of Network and Computer Applications*, 36(5), pp. 1275–1286, 2013.
- [7] E.J. Jang, R. Woo, D.S. Han, “Improvement of Connectivity between Infrastructure and Consumer Devices for Infotainment Services”, *IEEE Transactions on Consumer Electronics*, 59(2), pp. 329–334, 2013.
- [8] G. Bianchi, L. Fratta, M. Oliveri, “Performance evaluation and enhancement of the CSMA/CA MAC protocol for 802.11 wireless LAN’s”, *Seventh IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, pp. 392–396, October 1996.
- [9] C. Campolo, A. Molinaro, A. Vinel, “Understanding adjacent channel interference in multi-channel VANETs”, *IEEE Vehicular Networking Conference (VNC)*, December 2014, pp. 101–184.
- [10] “IEEE 1609.4-2010, IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Multi-channel Operation,” Feb. 2011.
- [11] IEEE Std. 802.11-2012: “IEEE Standard for Information technology - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications”.