Analysis of the Impact of Cognitive Vehicular Network Environment on Spectrum Sensing

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Abstract. The Cognitive Vehicular Network (CVN) has emerged as a promising solution providing additional resources and allowing spectrum efficiency. However, vehicular networks are highly challenging for spectrum sensing due to speed, mobility and dynamic topology. Furthermore, these parameters depend on the CVNs' environment such as highway, urban or suburban. Therefore, solutions targeting CVNs should take into consideration these characteristics. As a first step towards an appropriate spectrum sensing solution for CVNs, we first, provide a comprehensive classification of existing spectrum sensing techniques for CVNs. Second, we discuss, for each class, the impact of the vehicular environment effects such as traffic density, speed and fading on the spectrum sensing and data fusion techniques. Finally we derive a set of requirements for CVN's spectrum sensing that takes into consideration specific characteristics of CVN environments.

Keywords: Cognitive radio · CVNs · Spectrum sensing · Data fusion

1 Introduction

Recently, Vehicular Ad hoc Network (VANET) [1] has attracted a lot of interest from industries and research institutions, particularly with increasing number of vehicles on the road especially in urban area. VANET is a special kind of Mobile Ad hoc Networks MANETs that are applied to vehicular context. They provide Vehicle to Vehicle (V2 V) and vehicles to infrastructures (V2I) communications. On the opposite of MANET, in VANET the movements of vehicles are predictable due to the road topology. Besides, the high mobility leads to a higher probability of network partitions, and the end to end connectivity is not guaranteed [1]. The VANET applications can be classified into two categories: safety applications which provide the drivers with early warnings to prevent the accidents from happening, this represent the higher priority traffic, and user applications which provide road users with Network accessibility which represent traffic with less priority. Growing usage of applications such as exchanging multimedia information with high data in car-entertainment leads to overcrowding of the band and thereby giving rise to communication inefficiency for safety applications [1]. Furthermore, the 10 MHz reserved in the IEEE 802.11p standard as a common control channel is likely to suffer from large data contention, especially during peaks of road traffic [2], which might not provide sufficient spectrum for reliable exchange of safety applications. To alleviate this

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problem Cognitive Radio (CR) technology has been proposed [2]. The main role of CR is to allow the unlicensed users (a.k.a Secondary Vehicular Users: SVUs) to identify spectrum holes and exploit them without interfering with the licensed users (a.k.a Primary Users: PUs). This makes the spectrum sensing (SS) a crucial function in CR networks. Even if spectrum sensing in CR networks is well studied, however the research solutions proposed in static CR networks may not be directly applicable to CVNs due to high dynamic networking environment.

The works in [3–5] provide comprehensive surveys about spectrum sensing in CVNs. The authors in [3] review the existing studies related to SS in CVNs and provide the open issues in this area. In [4, 5], the authors provide an overview of distributed and centralized cooperative SS for CVNs and review some challenges and open issues in CVNs. In this paper, we provide an overview of spectrum sensing mechanisms and we propose a classification for existing CVN schemes. In fact, four classes are presented: centralized, distributed, partially centralized and integrated schemes. Indeed, the main characteristic that influences the spectrum sensing mechanisms used in CVNs is the changeable topology of vehicular environment which may be urban, suburban or highway area. The common features of these vehicular environments are the vehicles speed, fading and traffic density. But, the effect of these features differs from vehicular environment to another. Therefore, we analyze for each class the impact of the characteristics of each vehicular environment including speed, fading and traffic density on the SS techniques and data fusion techniques used to combine the reported or shared sensing results for making a cooperative decision. This analysis allowed us to derive the main spectrum sensing requirements in CVNs. The rest of this paper is structured as follows: in Sect. 2, we present background information on CVNs and we present the most used spectrum sensing techniques. In Sect. 3, we classify the existing CVNs sensing schemes. In Sect. 4, we analyze the environment effects on the sensing mechanisms used by these classes and we derive the corresponding spectrum sensing requirements for each environment. Finally, we draw final conclusions in Sect. 5.

2 Background on CVNs and Spectrum Sensing

2.1 Cognitive Vehicular Networks

The CVNs are composed of vehicles equipped with the CR system, allowing SVUs to change their transmitter parameters based on interactions with the environment in which they operate. Similarly to the traditional CR, The execution of CVNs is defined by a cycle which is composed by four phases: observation, analysis, reasoning and act [6]. Observation consists of sensing and gathering the information (e.g. modulation types, noise, and transmission power) from its surrounding area in order to identify the best available spectrum hole. In analysis phase, after sensing, some parameters have to be estimated (e.g. interference level, path loss and channel capacity). In reasoning phase, the best spectrum band is chosen for the current transmission considering the QoS requirement. The optimal reconfiguration is finally done in Act phase. But, the main novel characteristic that differentiates CVNs from the traditional CR is the nature of SVUs mobility. In one hand, due to road topology and usage of navigational systems, the vehicles can predict the future position and then it can know in advance the spectrum resources available on its path. On the other hand, the mobility increases spatial diversity in the observations taken on the different locations. This may influence the sensing performance. Furthermore, fast speed increases the number of collected samples which improves the sensing performance and requires less cooperation from other SVUs [7]. But, when the high fading (i.e. correlated shadowing) and the presence of obstacles are taken into account, the correlated samples affect the performance [8]. Besides, with faster speed the SVUs will have a higher probability to miss detect the PUs, because the PU will be outside the sensing range of SVU very quickly [9]. In addition, another parameter which can affect particularly the cooperation is the traffic density; the road topology becomes congested with dense traffic which declines the speed and the vehicles tend to be closer to each others, this decreases the performance due to correlation [8]. Thus, the main features of vehicular environment which influence the sensing are speed, fading, traffic density and the obstacles. These parameters vary according to the area type (i.e. urban, suburban, or highway).

The urban area is characterized by high fading, and dense traffic with low speed (around 50 km/h). The main features of suburban area are light traffic with medium speed, surrounded by some buildings which give rise to fading. The highway area is characterized with few surrounding structures which decline the fading effect, and vehicles can exceed 120 km/h [10].

2.2 Spectrum Sensing Techniques

The Spectrum Sensing (SS) techniques are divided into two types local SS (performed individually) and Cooperative Spectrum Sensing (CSS) [11]. Depending on the availability of the knowledge about the Primary Users (PUs), the local SS techniques can be classified into two main classes: informed and blind SS techniques [12].

2.2.1 The Local Informed Sensing Techniques

These techniques require the prior knowledge about PU's features such as sine wave carriers, hopping sequences, pulse trains, repeating spreading, modulation type etc. [12]. In addition they are robust to noise uncertainties, but their implementation is complex. In the informed techniques, we mention Matched Filtering Detection (MFD) [12] and Cyclostationary Detection (CD) [12]. The MFD could achieve the higher sensing accuracy with less sensing time, whereas sensing accuracy in CD requires long sensing time and it is not capable to differentiate the PUs from the secondary users.

2.2.2 The Local Blind Sensing Techniques

The blind techniques don't require any information about the primary signal. Among these techniques: Energy Detection (ED) [12], Eigenvalue-based Detection (EBD) [12] and the Compressed Sensing (CS) [11]. They present the advantage of requiring less sensing time. Even if the ED is the most popular technique due to its simplicity, it is the worst performer technique, especially in the case of noise uncertainty. The EBD deals well with noise uncertainty than the ED, while the CS facilitates wideband SS, and reduces the channel switching overhead of narrowband SS. However the CS incurs additional hardware cost and computational complexity [11].

2.2.3 Cooperative Spectrum Sensing

The Cooperative Spectrum Sensing (CSS) has been proposed in [11] and [13] to improve the performance of SS under fading environment conditions which is especially in the case of vehicular channels characterized by a strong fading. The key concept of CSS is to exploit spatial diversity among observations made about the status of channel by multiple SVUs [11]. The process of CSS requires the use of some techniques such as: local observations using individual sensing techniques, cooperation models, eventually a user selection technique can be used, reporting, and data fusion [11]. However the gain of CSS is limited by cooperation overhead which includes: sensing delay, shadowing, energy efficiency, mobility and security [11].

Table 1. Summary of SS techniques

	Blind SS techniques			Informed SS techniques	
	ED	EBD	CS	CD	MFD
Sensing time	short	medium	short	long	short
Performance	low	high	high	high	high

3 Classification of the Spectrum Sensing Schemes in CVNs

In literature, CVNs are usually based on the cooperative spectrum sensing, but can also integrate a geo-localization database to assist the traditional SS. Hence, in this section, we classify these spectrum sensing schemes in CVNs into four classes: centralized, distributed, partially centralized and integrated. And we identify the SS and fusion techniques used in these classes (Table 2).

3.1 Centralized CVN Schemes

In centralized CVN schemes, a central node act as fusion center (FC) that controls the process of cooperation. In the case of V2I a fixed node such as RSU (Road Side Unit) or BS (Base Station) acts as a FC [14, 15]. But, having a fixed FC may not be always possible in the case of CVNs. Thus, some works focus on a clustering strategy where the vehicles are selected to act as a FC cluster head [16, 17]. The cooperation process is defined as follow: Firstly, the SVUs sense the channels selected independently by the FC using Compressed Sensing (CS) in [14], Eigenvalue-Based Detection (EBD) in [15] and Energy Detection (ED) in [17]. The FC combines the local sensing received from SVUs for making a final decision by using the data fusion techniques such as Hard Fusion (HF) [14, 17], Soft Fusion (SF) [15] or Hidden Markov Model (HMM) [16]. Using SF at FC provides better sensing accuracy than HF [11], because the SVUs report to FC the entire local sensing samples. However it incurs control channel overheads in terms of time and energy consumption especially with large number of cooperating

SVUs. While, the HF requires much less control channel because the SVUs report to FC one decision bit (0 or 1), the performance can be decreased. While, the HMM is used to speed up the detection of PUs by indicating to FC the observations' number that should be received before making the fusion [16]. Once the final decision is made, the FC broadcasts it to SVUs.

3.2 Distributed CVN Schemes

Works in [18–20] focus on using decentralized CVN architectures where SVUs are cooperating in a distributed way. In [18], a distributed scheme based on the belief propagation algorithm is proposed specifically for highway, where each SVU senses the spectrum independently. Then, each vehicle combines its own belief with information received from other neighbors and a final decision can be generated after several iterations. In [19] the road topology is taken into account, where the highway road is divided into equal short segments which can be recognized with a unique identifier. Periodically, each SVU senses the spectrum, stores the results in its internal memory and share it later to inform others vehicles about spectrum holes in their future segments. This framework is further enhanced in [20] by an experimental study. The measurements are undertaken from moving vehicle travelling under different urban conditions and vehicular speeds. And then, a cooperative spectrum management framework is proposed, where the correlated shadowing is taken into consideration. Data fusion in [19, 20] is based on a weighted algorithm.

3.3 Partially Centralized CVN Schemes

The partially centralized CVN schemes [21, 22] are composed of two sensing levels. The first level is fast sensing (generally energy detection) performed by a central node [21] or by a set of selected nodes using cooperation [22]. In the second level, the requesting vehicles (RVs) rescan the list of holes received from coordinators using fine sensing such as cyclostationary detection [21, 22]. This may reduce the overhead of identifying all holes. Besides, the RVs use the sensed holes without seeking permissions from the coordinator. This scheme is then a partially unshackle master/slave sensing relationship between FC and SVUs.

3.4 Integrated CVN Schemes

In CR the integrated concept is based on the use of a geo-localization database. This later is described in [23] as a spectral map of available channels in a given geographical area, that can be provided to secondary users according to their location. However, its implementation may not be suitable for CVNs when road traffic is congested which leads to many vehicles trying to query the database. Thus, to mitigate the problems above, the use of database is combined with traditional sensing [24, 25]. In [24], in each segment of the highway, the vehicles should dynamically select their role (Mode I, Mode II or Sensing-only) according to the traffic load. In low traffic, vehicles choose the mode II to access the spectrum database through an internet connection. In mode I the vehicles get informed from vehicles on mode II. While in high traffic, the vehicles perform Sensing-only and cooperate to detect PUs. In [25], a BS is directly connected to a TV white space and database similarly to [24], the vehicles should dynamically select their role but this time according to the traffic load and the coverage of BSs.

Table 2. Summary of classification of CVN schemes

Classes	Ref.	Coordinator nodes	Sensing technique	Data fusion algorithm	Road Topology
Centralized	[14]	Base station	Compressed sensing	Hard fusion	Highway
	[15]	Base station	Eigenvalue-based detection	Soft fusion	Not specified
	[16]	vehicle	Not specified	Hidden markov model	Not specified
	[17]	Three vehicles	Energy detection	Hard fusion	Highway/ Suburban
Distributed	[18]	Coordination is not needed	Not specified	Belief algorithm	Highway
	[19]		Energy detection	Weighted algorithm	Highway
	[20]		Energy detection	Weighted algorithm	Urban
Partially centralized	[21]	RSU or vehicle	– Energy detection at coordinator – Fine sensing at RVs[a]	Data fusion is not needed	Highway
	[22]	Three vehicles	– Cooperation among coordinators – Fine sensing at RVs[a]	Hard fusion (Majority rule)	Highway/ Suburban
Integrated	[24]	Coordination is not needed	Dynamic detection: Mode I, Mode II or Sensing-only (local or cooperative detection)	Data fusion is not needed	Highway
	[25]			Hard fusion (Majority rule)	Not specified

[a] RVs: Requesting Vehicles

4 Derived Requirements of Spectrum Sensing in CVNs

As seen in previous section each area has its own features including speed of vehicles, traffic density, and the surrounding obstacles. In fact, the spectrum sensing accuracy depends on the vehicle's speed, traffic density and the channel fading. To the best of our knowledge, the conditions of the surrounding area are not taken into account in literature. In this section, we first analyze the impact of the vehicular environment (i.e. highway, Suburban and Urban), especially the effect of traffic density, mobility and fading, on both spectrum sensing and fusion techniques for each class. Second, we derive the corresponding spectrum sensing requirements for each environment.

4.1 The Impact of CVN Environment on the Local Spectrum Sensing

The detection techniques for local spectrum sensing include cyclostationary detection (CD), matched filtering detection (MFD), energy detection (ED), compressed detection (CS) and eigenvalue-based detection (EBD). Each of these techniques has its pros and cons in terms of sensing time and performance as shown in Table 1. Thus, the choice of the appropriate SS according to the environment properties is very important.

In highway context, high speed requires fast detection (ED, CS and MFD). However, ED could be used for open space but with high fading, it is better to use the fast and accurate detection (CS or MFD). In suburban context, the speed is light which can affect the sensing performance, and fading effect is more challenging than highway context. Thus, in these cases the fast and accurate detection (CS or MFD) is favored. Whilst in urban context, the fast detection is not necessary due to low speed, but the accurate detection (EBD, CS, MFD or CD) is required due to strong fading.

4.2 The Impact of CVN Environment on Data Fusion of the Centralized Schemes

Generally, the cooperative spectrum sensing schemes are a composition of local SS and data fusion. As previously mentioned, each fusion technique in centralized schemes such as soft fusion (SF), hard fusion (HF) or hidden Markov model (HMM), has its pros and cons in terms of delay and overhead. Thus, we have to carefully choose the appropriate fusion techniques according to the environment properties.

In highway context, the data fusion such as HF and HMM present the advantage of fast fusion, but due to low density, sometimes there will not be enough vehicles to cooperate for sensing, thus the SF is preferred. In suburban context, the traffic density effect is challenging than highway context. Thus, it is better to use fast fusion. While in urban context, the fast fusion is vital due to high traffic.

4.3 The Impact of CVN Environment on Data Fusion of the Distributed Schemes

The data fusion techniques which may be used in distributed schemes are belief algorithms and weighted algorithms. In belief algorithm, the data from different cooperating vehicles is merged considering the spatial and temporal correlation of different observations hence the performance of this algorithm will be affected by fading (i.e. correlated shadowing). Furthermore, belief procedure is rather time consuming when larger number of SVUs participate in the process. While in weighted algorithm, the data is merged using weights and only if the correlation between the sensing samples of two vehicles are below a given threshold. Besides, the performance of weighted algorithm degrades under low density.

In highway context with open space, belief algorithm performs well under low density. But, if fading is considering this algorithm is not preferred. In both suburban and urban contexts, the data fusion techniques are affected by dense traffic and fading.

Hence in this case, it is better to use the selection of cooperating nodes (i.e. correlation selection) either to reduce the number of cooperating SVUs and to select the uncorrelated SVUs. Generally, for both urban and suburban contexts, belief algorithm may not be suitable due to fading and high traffic density. While, weighted algorithm is required because it performs well under dense traffic.

4.4 The Impact of CVN Environment on the Partially Centralized Schemes

As mentioned in Sect. 3, in the partially centralized, the first level (i.e. fast sensing) is based on the local sensing at the coordinator or at a subset of selected coordinators. At second level (i.e. fine sensing), it is possible to use cyclostationary detection (CD) or eigenvalue-based detection (EBD).

In highway context, to speed up the detection at first level it is required to use fast detection or both fast and accurate detection according to fading effect. While in the case of cooperation at first level, it is possible to use fast fusion. At second level, it is better to use EBD because sensing time of EBD is less than CD. In suburban and urban context, it is favored to use at first level the cooperation among the coordinators to alleviate the problem of hidden PU due to presence of obstacles. At second level, it is required to use EBD in the suburban context because the effect of speed is considered, while in the urban context it is possible to use CD and EBD.

4.5 The Impact of CVN Environment on the Integrated Schemes

For integrated schemes, an optimal ratio between querying the spectrum database and sensing according to the traffic density and BSs coverage is required. In dense traffic the SVUs perform in sensing-only mode (local SS or cooperative sensing). The accuracy in this mode is also important; hence the choice of the appropriate sensing and fusion techniques depends on the environment requirements as mentioned above in Subsects. 4.1, 4.2 and 4.3. Generally, in highways, it is preferred to use mode I and mode II due to low traffic density. While in suburban and urban context, it is possible to use sensing-only mode due to high traffic density. However, as mentioned above, due to the hidden PU issue it is better to use cooperative spectrum sensing (CSS) at sensing-only mode.

4.6 Summary of Spectrum Sensing Requirements in CVNs

The main constraints in urban and suburban context are hidden PU, strong fading and dense traffic. The hidden PU issue requires CSS among SVUs, but due to fading and dense traffic a correlation selection is very important. The cooperation in highway context is affected by fast speed and low density, thus the accurate SS techniques with short sensing time at local SS are required such as matched filtering detection (MFD) or compressed detection (CS). The fusion techniques in CSS (centralized or distributed) should be adequate with the surrounding environment. For example, soft fusion (SF) and belief algorithm are favored in low traffic, while, hard fusion and weighted algorithm are required in dense traffic. In contrast, we can observe that these requirements are not always respected in literature, as in [14] where the CS with hard fusion (HF) is considered for highway. Hence the effect of low density is not taken into account by using HF. In [17], the energy detection (ED) with HF is considered applicable for both highway and suburban, which could not be optimal since SF is preferred for highway and ED does not provide the required accuracy in urban context. Furthermore, the schemes in [15, 16] are considered applicable for all contexts, and in [16] the SS technique is not also specified.

Therefore, the real features of the surrounding area are not studied well in the literature either for centralized or distributed CVNs. Generally, it is important to use adequate SS and fusion techniques according to the properties of the surrounding environment. Furthermore the restricted and predictable mobility is not addressed for improving the SS accuracy (Table 3).

Table 3. Summary of spectrum sensing requirements in CVNs

Classes	Context		
	Highway	Suburban	Urban
Centralized	Fast and/or accurate local detection with soft fusion	Fast and accurate local detection with fast fusion	Accurate detection and fast data fusion.
Distributed	Fast and/or accurate local detection with belief algorithm	– Fast and accurate local detection – Weighted algorithm	– Accurate local detection – Weighted algorithm with correlation selection
Partially centralized	– First level:local SS or CSS – Second level: EBD	– First level: CSS (fast local detection with fast fusion) – Second level: EBD	– First level: CSS (fast local detection with fast fusion). – Second level: EBD or CD
Integrated	Mode I and Mode II	Sensing-only mode (CSS)	Sensing-only mode (CSS)

5 Conclusion

In this paper, we have analyzed the impact of environment effects (traffic density, speed and fading) on spectrum sensing and fusion techniques applied in CVNs. And then, we have derived the main spectrum sensing requirements in CVNs. This analysis enabled us to conclude that the real effects of vehicular environment are not studied well in literature for CVNs, this motivate further research needed for practical implementation. Thus, our discussions on the environmental effects on CVNs are needed to be grounded in established empirical studies as a part of future directions pertaining to CVNs. In our future work, we will be interested in spectrum sensing in urban context. Firstly, because the spectrum sensing in urban context is not studied well and secondly there are many challenging constraints in urban context such as high traffic, high fading and the PU's hidden problem. However, exploiting advantageously the predictable mobility may enhance the spectrum sensing performance.

References

1. Toor, Y., Muhlethaler, P., Laouiti, A., De La Fortelle, A.: Vehicle ad hoc networks: Applications and related technical issues. IEEE Commun. Surv. Tutor. **10**(3), 74–88 (2008)
2. Ghandour, A.J., Fawaz, K., Artail, H.: Data delivery guarantees in congested Vehicular ad hoc networks using cognitive networks. IEEE IWCMC **2011**, 871–876 (2011)
3. Abeywardana, R.C., Sowerby, K.W., Berber, S.M.: Spectrum sensing in cognitive radio enabled vehicular ad hoc networks: a review. In: IEEE ICIAfS, pp. 1–6 (2014)
4. Ahmed, A.A., Alkheir, A.A., Said, D., Mouftah, H.T.: Cooperative spectrum sensing for cognitive vehicular ad hoc networks: an overview and open research issues. CCECE **2016**, 1–4 (2016)
5. Chembe, C., Noor, R.M., Ahmedy, I., Oche, M., Kunda, D., Liu, C.H.: Spectrum sensing in cognitive vehicular network: state-of-Art, challenges and open issues. Comput. Commun. **97**, 15–30 (2017)
6. Singh, K.D., Rawat, P., Bonnin, J.M.: Cognitive radio for vehicular ad hoc networks (CR-VANETs): approaches and challenges. EURASIP J. Comm. Netw. **2014**, 49 (2014)
7. Min, A.W., Shin, K.G.: Impact of mobility on spectrum sensing in cognitive radio networks. CoRoNet@MobiCom 2009, pp. 13–18 (2009)
8. Zhu, S., Guo, C., Feng, C., Liu, X.: Performance analysis of cooperative spectrum sensing in cognitive vehicular networks with dense traffic. VTC Spring **2016**, 1–6 (2016)
9. Zhao, Y., Paul, P., Xin, C., Song, M.: Performance analysis of spectrum sensing with mobile SUs in cognitive radio networks. IEEE ICC **2014**, 2761–2766 (2014)
10. Mecklenbrauker, C., Karedal, J., Paier, A., Zemen, T., Czink, N.: Vehicular channel characterization and its implications for wireless system designs and performance. IEEE Trans. Veh. Technol. **99**(7), 1189–1212 (2011)
11. Akyildiz, I.F., Lo, B.F., Balakrishnan, R.: Cooperative spectrum sensing in cognitive radio networks: a survey. Phys. Commun. **4**(1), 40–62 (2011)
12. Axell, E., Leus, G., Larsson, E.G., Poor, H.V.: Spectrum sensing for cognitive radio: state-of-the-art and recent advances. IEEE Signal Process. Mag. **29**(3), 101–116 (2012)
13. Ghasemi, A., Sousa, E.S.: Collaborative spectrum sensing for opportunistic access in fading environments. In: First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, pp. 131–136. USA (2005)
14. Duan, J.Q., Li, S., Ning, G.: Compressive spectrum sensing in centralized vehicular cognitive radio networks. Int. J. Future Gener. Comm. Netw. **6**, 1–12 (2013)
15. Souid, I., Chikha, H.B., Attia, R.: Blind spectrum sensing in cognitive vehicular ad hoc networks over nakagami-m fading channels. IEEE CISTEM **2014**, 1–5 (2014)
16. Brahmi, I.H., Djahel, S., Ghamri-Doudane, Y.: A hidden markov model based scheme for efficient and fast dissemination of safety messages in VANETs. In: IEEE GLOBECOM, pp. 177–182 (2012)
17. Abbassi, S.H., Qureshi, I.M., Abbasi, H., Alyaie, B.R.: History-based spectrum sensing in CR-VANETs. EURASIP J. Wirel. Comm. Netw. **2015**(1), 163 (2015)
18. Li, H., Irick, D.K.: Collaborative spectrum sensing in cognitive radio vehicular ad hoc networks: belief propagation on highway. VTC Spring **2010**, 1–5 (2010)
19. Di Felice, M., Chowdhury, K.R., Bononi, L.: Analyzing the potential of cooperative cognitive radio technology on inter-vehicle communication. Wirel. Days, 1–6 (2010)
20. Di Felice, M., Chowdhury, K.R., Bononi, L.: cooperative spectrum management in cognitive vehicular ad hoc networks. IEEE VNC **2011**, 47–54 (2011)
21. Wang, X.Y., Ho, P.H.: A novel sensing coordination framework for CR-VANETs. IEEE Trans. Veh. Technol. **59**(4), 1936–1948 (2010)

22. Abbassi, S.H., Qureshi, I.M., Alyaei, B.R., Abbasi, H., Sultan, K.: An efficient spectrum sensing mechanism for CR-VANETs. J. Basic Appl. Sci. Res. **3**, 12 (2013)
23. Pagadarai, S., Wyglinski, A.M., Vuyyuru, R.: Characterization of vacant UHF TV channels for vehicular dynamic spectrum access. IEEE VNC **2009**, 1–8 (2009)
24. Di Felice, M., Ghandhour, A.J., Artail, H., Bononi, L.: Integrating spectrum database and cooperative sensing for cognitive vehicular networks. IEEE VTC Fall **2013**, 1–7 (2013)
25. Doost-Mohammady, R., Chowdhury, K.R.: Design of spectrum database assisted cognitive radio vehicular networks. IEEE CrownCom **2012**, 1–5 (2012)