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Vehicular Ad- Hoc Networks (VANETs) Assisted by Cognitive Radio Technology: Current Prominence, Challenges, and Explore Trends- A Survey

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ABSTRACT

VANET and cognitive radio network (CRN) are both new budding technologies in wireless networking. The application of CR concept in wireless communication systems for intelligent vehicles has been cause to be as a promising idea towards solving the problem of sparse spectrum. This paper discusses CR technologies for VANETs expected at opportunistic spectrum access (OSA) for improved vehicular communication efficiency. This survey explored novel approaches and current research challenges coupled with the use of CR technologies in VANETs. Our study is different from previous works in that it presents latest advances, open issues, and future research directions on how to efficiently design and organize CR enabled vehicular networks emphasizing on architecture, CR-VANETs and WAVE Standards, MAC schemes for CR-VANETs, spectrum sensing, minimized intrusion impact through coordination between PUs and SUs, spectrum management, efficient message routing, security and privacy, with CR enabled vehicular networks test-beds and simulation platforms. Furthermore, the paper also identified several challenges facing the design and development of CR-VANTs and the required approaches to gear them.

KEYWORDS: Cognitive Radio-VANETs, WAVE, Cognitive Radio, Spectrum Sensing, Control Channel, V2I, V2V, service channel.

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I. INTRODUCTION

The budding CR technology has been identified as the solution to the issues of spectrum scarceness and the under utilization of the available spectrum. The primary idea behind this emerging technology is to allow the Secondary (unlicensed) Users (SUs) to allocate the available spectral resource of the Primary (licensed) Users (USs) without causing destructive interference to the rightful licensed users[1]. In other words, CR devices intelligently detect spectrum gap (also known as spectrum availability) and allocate the spectrum bandwidth to suitable SUs for effective utilization without causing intervention to the licensed users [1,2]. CR devices are capable of adapting to their internal states by sensing their surrounding locality and making changes in certain operating parameters, accordingly. The concept of CR was first planned by Mitola and Maguire [3]. The authors proposed a Radio Knowledge Representation Language (RKRL) with CR to intelligently operate the protocol stack so as to adapt and efficiently satisfy the user requirements. This changes radio stations from simple blind executors of pre-defined protocols into smart radio domain nodes that dynamically deliver services with the awareness of CR technology.

Nowadays, the ever-increasing number of vehicles on the motorways has brought focus on improving road safety and in- vehicle activity. Vehicular networks also referred to as VANETs have been foreseen as an important application with giant societal impact [4,5] which includes road safety, traffic efficiency and infotainment services. Efficient, dependable, and timely exchange of current and upcoming traffic information among moving vehicles can reduce road accidents, minimize hours spent on the motorways due to traffic jams, and reduce fuel utilization. Other applications of VANETs contain location-based, and road side information services such as information about gas stations, road side restaurants, parking, road side lodges, etc. The IEEE 1609.4 [6] protocol stack which was projected by a delegated IEEE Working Group (WG) is meant to supply mechanism for multi-channel operations in wireless access for vehicular environments (WAVE), where all the seven channels (i.e., one control channel (CCH) and, six service channels (SCH)) are cyclically synchronized at intervals for efficient message transmission. The United States' central Communication Commission (US FCC) made the pioneering step to support vehicular networks by allocating 75 MHz spectrum in the 5.9 GHz spectrum band for the WAVE system. In other words, all vehicular users will have to vie for the channel access and use it to exchange both safety and non-safety related information in the 5.9 GHz spectrum band. However, in order to realize the full potentials of VANETs, vehicles should be able to communicate with one another using vehicle to vehicle (V2V), vehicle to roadside communications (V2I), and vehicle to other pedestrians' handheld devices (V2X) relations by leveraging on the wide range of wireless spectrum, and networks such as Wi-Fi networks, cellular networks, TV bands, and satellite networks, depending on the availability, and position of vehicles. Fig. 1 illustrates a V2V communication circumstances with CR enabled vehicles which enables opportunistic spectrum usage while moving with the recent advances in cognitive radio (CR) technology [7,8] introduction of CR enabled VANETs will enable opportunistic spectrum sensing, and hopping from one frequency to another in the entire spectrum range based on their requirements, and operating environment.

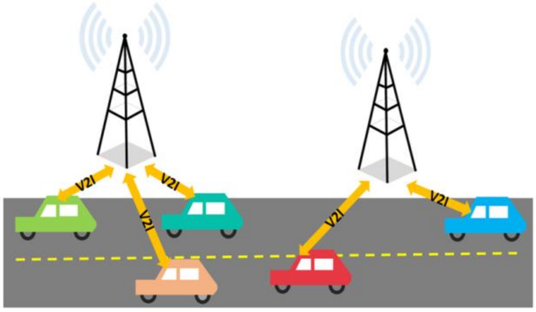

Fig. 1: V2V Communication Scenario with CR Enabled Vehicles.

It is essential to point out that in designing CR enabled vehicular networks, attention must be paid to the strange characteristics of vehicular communication networks such as high speed of vehicles, high density in urban areas, and extremely dynamic topology of vehicular networks due to high mobility of the vehicles, which may direct to challenges of choosing suitable network, communication channel or data rate.

The principal contributions of this study area in four folds and are listed as follows: (i) the summary of the recent advances in CR technology and VANETs are discussed; (ii) the challenges and techniques already accepted for designing CR enabled vehicular networks are also investigated; (iii) the open issues and current research directions for future development and deployment of CR enabled vehicular networks are presented; and (iv) the performance parameters for different CR enabled vehicular network applications are surveyed and accessible.

The remuneration and potentials of CR technology in vehicular networks cannot be over emphasized. In several cases, motor highways especially in rural areas are open spaces with completely high chances of finding a radio spectrum hole that can be accessed opportunistically by CR equipped vehicles. This is unlike sub-urban and urban areas where there are very slight chances of finding radio spectrum holes as a result of high population which in turn leads to high usage of TV white space. Hence, the combination of these two emerging technologies can resolve the problem of scarce, limited, insufficient spectrum bandwidth, and under utilization of available spectral resource for vehicular communication systems.

Table :1 Challenges and required approaches for CRAVNETs

Challenges	Required approaches
Scarce Spectrum	Efficient use of spectrum
High message delivery reliability	QoS support
Scalability for accommodating newer technologies	Reprogrammability
Highly dynamic topologies	Algorithms with fast convergence time
Dynamic environment and spectrum availability	Machine learning algorithms

II. CHALLENGES AND APPROACHES FOR Cognitive Radio ENABLED VEHICULAR NETWORKS

The improvement and deployment of vehicular networks faces lacking radio spectrum bandwidth allocations issues as a result of the random number of mobile users in the application. In tune with the ever-increasing demand of this random number of vehicle, there will soon be a rapid rise in development of new safety related and non-safety related applications and services for vehicular environments. Some of the examples of these applications include collision avoidance, safety and traffic monitoring, multimedia streaming, and applications for data collection for smart cities, V2V, V2I, V2X, and infrastructure-to-infrastructure (I2I) communication. With the anticipated explosion of the above applications in near future, the design and implementation of CRN technology in vehicular networks has been assumed to further enhance efficient spectrum bandwidth distribution model in VANET to hold the applications. Taxonomy of recent advances on CR supported Vehicular NETwork (CRAVNET) [1] is represented in Fig. 2 and further more explored in strength in this section.

A. WAVE Standards and CR assisted Vehicular Networks:

Vehicular network is a particular type of mobile ad-hoc networks (MANETs), where intelligent vehicles in VANETs usually represent high mobility nodes with a highly dynamic network topology. On the other hand, CR technology is a model newly devised to address the challenges of radio spectrum insufficiency in communication networks. WAVE Physical Layer is based on the IEEE 802.11, on the other hand, because of the operating environment of vehicular networks; an amendment of the standard is made which is known as IEEE 802.11p [2, 6]. Although mobile stations in vehicular networks travel in a random approach in line with the roads patterns, spectrum bandwidths are heavily occupied and utilized in urban areas, which are usually high density environments whereas sub-urban (or rural) areas are usually less density environments with many spectrum bandwidths unoccupied and under utilized most of the time. Hence, incorporating CR technology into VANET will help in solving the problem of scarce and insufficient spectrum allocation for vehicular network communication through opportunistic spectrum access of the idle and underutilized spectrums. Table 1 prove challenges and required approaches for CRAVNETs

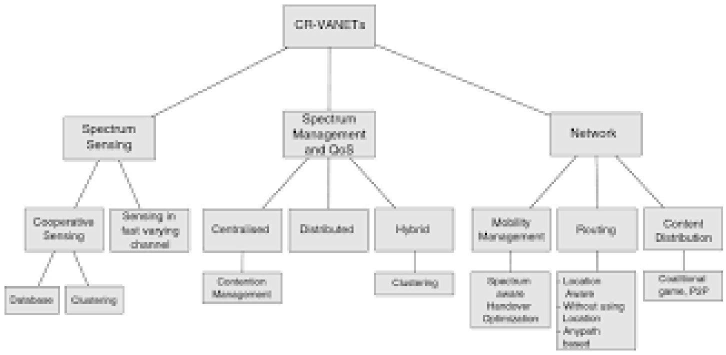

Fig. 2: Taxonomy of recent advances on CR assisted vehicular networks.

In order to solve the challenges of high spectral congestions in CRAVNETs, the authors in [9] proposed a CR system that can temporarily and spatially add extra radio channels to vehicular networks in the face of high vehicular density especially during the do too quickly hours when roads are usually heavily jam-packed. The proposed CR framework accords the highest priority to critical safety messages while ensuring that non- safety VANET applications (with non-safety messages) are also successfully transmitted with less delay and increased overall network performance. Likewise Tsukamoto et al [10] proposed a distributed channel coordination scheme for V2V message to exploits the range of different communication frequencies and increase the data transmission rate of both intra and inter-vehicle communications.

In Fawaz et al [11], a novel system is introduced to enlarge the spectrum bandwidth allocation to CCH of wireless access in vehicular environment (WAVE) [12] protocols efficiently through the use of cognitive network principles. Finally, the processing unit then deduce data conflict locations and generates radio spectrum bandwidth schedules that will be dispatched to the passing smart vehicles. In [13], the authors opine that radio spectrum shortage has now turned the most critical challenge facing VANETs. Improved wireless architectures and its applications on vehicular networks, and the consumption of CR technology to seek out better radio spectrum reuse through ad hoc, peer-to-peer (P2P), and multi-hop communication results are addressed in Gerla and Kleinrock [13].

B. MAC Protocols for CR assisted Vehicular Networks:

Wireless MAC protocols provide channel admission mechanisms in CR assisted vehicular networks. The main unique characteristic with value to the radio environmental conditions in which the Cognitive Radio Network operates is the time/frequency/space-dependent availability of the spectral resources, a trend commonly referred as spectrum heterogeneity. The design and effective implementation of multi-channel MAC protocols with the ability of supporting concurrent message transmissions through fair allocation of the available channels with each beacon interval may not be sufficient in CR assisted vehicular networks due to the fast-fading feature connected with vehicular network environment. On the other hand, wireless MAC protocols designed based on OSA for the selection of available channels at every individual transmission may not guarantee reasonable and efficient share of presented spectrum bandwidth between the challenging CR assisted SUs. In result solutions to these challenges, Chung et al. [14] projected a cognitive MAC method for vehicular networks. The cognitive MAC method uses both short-term and long-term radio spectrum access to guarantee fair spectrum share (i.e., fair allocation of the additional spectrum amongst the challenging CR assisted SUs). In addition, the proposed channel access scheme exploits multi-user diversity so as to achieve high network throughput.

In a similar study, Shah et al. [15] adopted the CR concept and the enhanced distributed coordination access (EDCA) to propose a MAC protocol for WAVE in order to develop the overall utilization of the available channel (s) and satisfy the high transmission consistency demand associated with vehicular safety messages. However, the dynamic MAC protocol was planned for common VANET. Hence, in order to guarantee a significant boost in channel access reliability, minimized transmission delay, and overall network throughput while concurrently agreeable the QoS requirement, a dynamic channel access (i.e., MAC) scheme precise to CR assisted vehicular networks must be planned and implemented.

C. Security, Privacy, and Liability for CR-VANETs :

Security and privacy issues are extremely essential for effective design, implementation, and successful operation of CR enabled VANETs due to potential threats to traffic flow, properties, and human lives by any cruel attempt, for instance, fake (or fraudulent) message transmission leading to traffic disruption and fatal accidents. Some of the security and privacy challenges connected to security, privacy, anonymity, and responsibility in CR assisted vehicular networks have been explored in [12, 16]. Vehicular networks supply wireless access for random vehicles to communicate and exchange both security and non-safety related information on the road, whereas CRNs enable efficient sharing of available spectrum bandwidth between these random vehicles. Hence, guaranteeing security, privacy, secrecy, and liability in CR assisted vehicular networks remains one of the keys headed for making CR enabled vehicular networks a reality. The distributed sensor technology assist to guarantee high reliability and optimality of the proposed protocol, and prioritizes efficient QoS, robustness against denial of service (DoS) security attacks, and the prevention of data aging. In general, wireless access in vehicular network similar to other wireless networks is highly exposed to both DoS and distributed DoS security attacks, such as radio jamming attack.

Generally, common security threat to effective incorporation of CR technology in vehicular networks is jamming attacks, which can obstruct with legitimate wireless access communications to adversely affect and degrade the overall QoS of the vehicular network. In a related study, Hamieh et al.[18] conducted a study on how to identify radio interference attacks in vehicular networks. According to Hamieh et al.[18], a jammer sends out transmissions only when valid radio movement is signalled from its radio hardware to detect a given class of jamming attack. The security model proposed in [18] was used to effectively identify the presence of jamming attack.

Table : 2. Cooperative spectrum sensing (CSS) techniques

Ref. No.	Spectrum sensing technique	Common CCH	Data fusion	Aim
[1]	Arbitrary	WAVE CCH	Hybrid	Effective radio Spectrum detection and fair allocation more future road segments along vehicle's path
[10]	Energy detection	WAVE CCH	Hybrid	Prediction of radio channel availability in the next road fragment using historical sensing data mining
[12]	Fast sensing: energy detection, and Fine	WAVE CCH	Hybrid	Framework of coordinated spectrum sensing
[15]	Arbitrary	WAVE CCH	Hybrid	Effective radio Spectrum detection and fair allocation for QoS guarantee
[16]	Energy detection	Ideal	Distributed	Weighted consensus based CSS to tackle Spectrum Sensing Data Falsification security attacks
[17]	Maximum Likelihood Ratio	Ideal	Centralized	Improved performance of MLR detection over a wide band OFDM-based overlay CR-VANET.
[18]	Arbitrary	WAVE CCH	Distributed	Determination of the optimal CSS to radio spectrum database querying ratio
[19]	Energy detection	WAVE CCH	Distributed	Performance improvement of energy detection over complex Generalized-K (كم) fading to tackle both small
[20]	Arbitrary	Ideal	Centralized	Resolving the coexistence problem for a vehicular and an IEEE 802.22 network via resource allocation
[21]	Energy detection	WAVE CCH	Centralized	Provision of reliable adaptive spectral resource management for cognitive cloud based VANETs

D. Routing in C R-VANETs

Even though VANET is considered as a special kind of mobile ad hoc network (MANET), but due to the peculiar network characteristics of CR enabled vehicular networks such as frequent network disconnections, and varying network topology, existing conventional routing protocols designed for MANETs are not applicable for CR-VANETs. Most of the vehicular network routing algorithms are categorized into three, namely, opportunistic forwarding algorithms, geographic forwarding algorithms, and trajectory-based forwarding algorithms. Opportunistic forwarding algorithms adopts carrying-and- forwarding approach to receive and retain a message whenever given the opportunity until the mobile node meets the next hop node through which the message can be routed to its destination. This kind of algorithm is especially useful in wireless communication scenarios with regular network disconnections and can be combined with other routing mechanisms that use trajectory-based or geographic forwarding algorithms. On the other hand, geographic forwarding algorithm routes messages towards their destination node based on its geographical location. Although this type of message forwarding mechanisms is scalable, they are not capable for handling voids and dead-ends. Trajectory-based forwarding algorithms can be the most appropriate message routing algorithm for CR enabled vehicular networks since they regard as the road infrastructure as an overlay absorbed graph, using the roads as graph edges, and the road intersections as graph nodes to enable packets forwarding to move in pre- defined trajectories [8, 12].

Kim et al. [19] studied some of the restrictive factors of the existing routing protocols, where the sensed channel information, and geographical location are used to carry out a cognitive routing of the transmitted packets. The authors' use of the sensed channel information, and geographical location effected in overall network throughput improvement. The protocol they proposed uses unlicensed spectrum band to manage in a multi-hop communication, and wireless ad hoc mode, which is different from the traditional CR strategies. Through the application of diverse allocations of spectrum bandwidth in CR assisted vehicular network, both safety and infotainment messages are routed across the entire network so as to reach intended receivers. Barve and Kulkarni [20] addressed the challenges of packets routing in CRNs. The study determined on the problem of message forwarding in CRNs, which absorb identifying and maintaining the optimal path from the sender to receiver using the presented common channel. Further mechanism on routing solutions to suitable the deployment of CR assisted vehicular networks must be followed to solve the challenges of message forwarding in CR-VANETs.

III. CONCLUSION

This paper presents a survey of new advances and search several research challenges connected with the use of CR technology for vehicular networks. Although the design and consumption of CR technology in VANETs is still in its initial stage, CR enabled vehicular networks have great potentials in intelligent transportation systems (ITSs) in the next to future because of the enormous consumer market for vehicular communications. However, the existing research solutions designed for general-purpose CRNs are not straightly applicable to CR enabled vehicular networks because of the unique features of VANETs which must be put into consideration when manipulative the radio spectrum management functions for CR enabled vehicular networks. This paper has recognized several challenges and requirements for efficient design and exploitation of CR enabled vehicular networks. Furthermore, recent advances, open problems, and future research development on effective application of CR technology into VANETs were examined.

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