# Challenges and Prospects of Cognitive Radio-EnabledVehicular Ad Hoc Networks

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***Abstract :*** With the advent of wireless networking, two emerging concepts, namely Cognitive Radio Networks(CRN) and Vehicular Ad hoc Networks (VANETs), have garnered significant attention. Cognitive Radio Networks possess the ability to acquire knowledge of their operational geographical environment, enabling effective spectrum management between primary and secondary users. On the other hand, VANETs are instrumental in sharing emergency safety messages among vehicles to ensure the safety of road users. The integration of Cognitive Radio Networks in VANETs presents several advantages, including efficient spectrum utilization and enhanced VANET deployment support. However, this amalgamation also poses unique challenges. The random fluctuations in spectrum users, unpredictable nature of VANETs, high mobility of vehicles, varying interference levels, security concerns, packet scheduling, and priority assignment complexities demand careful attention. In this paper, we conduct an exhaustive survey and critical analysis of these challenges in cognitive VANET environments. Additionally, we discuss open issues, highlight key challenges, and propose performance metrics for diverse cognitive radio VANET applications to foster advancements in this domain**.**

***Index Terms* – CRN, Interference, Packet Switching, Priority Assignment, Velocity, VANET**

## I. Introduction

The increasing demand for wireless communication has led to a scarcity of available spectrum resources, necessitating innovative solutions to optimize spectrum utilization. Cognitive Radio Networks (CRNs) have emerged as a key technological advancement to tackle this challenge. The fundamental idea behind CRNs is to intelligently and dynamically allow both licensed (primary) users and unlicensed (secondary) users to share the same spectrum, ensuring efficient utilization without causing interference to authorized users. CR devices are designed to detect available spectrum and intelligently assign suitable users to occupy the bandwidth, adapting to their surroundings. The concept of Cognitive Radio was initially proposed by Mitola and Maguire in 1999, introducing the concept of intelligent radio agents that actively adapt to user needs and manipulate protocol stacks. Since then, CR technology has been continuously evolving, transforming traditional radio nodes into intelligent agents capable of delivering services with the realization of Cognitive Radio.

In the context of wireless vehicular communication, Cognitive Radio technology holds significant promise for Vehicular Ad hoc Networks (VANETs). VANETs aim to enhance road safety by facilitating the exchange of emergency safety messages among vehicles. Incorporating Cognitive Radio capabilities in VANETs offers several advantages, such as efficient spectrum utilization and improved deployment support. However, the implementation of efficient Cognitive Radio VANETs comes with its own set of challenges. Research studies have shown that a substantial portion of licensed spectrum remains underutilized, motivating the need for cognitive radio solutions. Addressing issues like the design of a common control channel, joint spectrum sensing, and cognitive implementation architecture becomes crucial for the successful development of Cognitive Radio Networks in VANETs. In this context, this paper conducts a comprehensive survey and critical analysis of the challenges faced in Cognitive Radio VANET environments, with a focus on open issues, performance metrics, and potential solutions for a wide range of Cognitive Radio VANET applications.

Vehicular Ad hoc Networks (VANETs) have emerged as a promising technology that addresses communication challenges among vehicles, particularly car-to-car communication. VANETs facilitate ad hoc multi-hop communication, connecting cars with diverse mobility patterns. Additionally, Vehicle-to-Infrastructure networks, also known as Vehicle-to-Roadside networks, utilize stationary Access Points or Base Stations to establish connections with moving vehicles, enhancing communication capabilities [2]. The primary objective of VANETs is to ensure road safety by enabling vehicles to exchange critical safety messages. Beyond safety applications, VANETs also offer opportunities for comfort applications, such as web browsing and multimedia data downloading [3]. To support the requirements of VANETs, various standards have been developed, including the Institute of Electrical and Electronics Engineers (IEEE) P1609 Wireless Access Vehicular Environment, Dedicated Short Range Communication, and IEEE 802.11p. [1]

However, with the increasing demand for VANETs, the scarcity of available spectrum resources has become a pressing concern. To address this issue, cognitive radio networks have emerged as a promising solution. Cognitive radio empowers VANETs to efficiently utilize spectrum resources while ensuring fair sharing among nodes, even under dynamic channel conditions with high mobile nodes. The unique and unpredictable nature of VANETs presents challenges in terms of scheduling efficiency, security, priority assignment, and managing high node mobility, all of which are crucial for the successful deployment of VANETs.

A notable framework proposed by [4] has proven influential in enabling spectrum sharing opportunities for Inter-Vehicle Communication (IVC) through cooperative sensing, spectrum allocation, and cooperation processes. This approach has demonstrated robustness in primary user detection even under fading conditions .The primary contributions of this research work encompass four key aspects. Firstly, it provides a comprehensive overview of the state-of-the-art cognitive radio network and VANET technologies. Secondly, it thoroughly explores the challenges encountered and presents various approaches to designing cognitive radio VANETs. Thirdly, the paper delves into the identification and discussion of open issues and potential research directions in the domain of cognitive radio VANETs. Lastly, the study analyses performance metrics relevant to diverse cognitive radio VANET applications.

The subsequent sections of this article are organized as follows: Section 2 presents an in-depth discussion on the current advancements in cognitive radio networks and VANETs. In Section 3, the challenges faced during the design of cognitive radio networks in VANETs are highlighted, along with potential approaches to tackle them. Section 4 focuses on exploring open issues and suggesting research directions for cognitive radio VANETs. The analysis of performance metrics for different cognitive radio VANET applications is presented in Section 5. Finally, Section 6 concludes the paper, summarizing the key findings and highlighting the significance of cognitive radio technologies in enhancing VANET performance and efficiency.

## II. PROSPECTIVE OF COGNITIVE RADIO BASED VANET

To address the issue of spectrum scarcity in VANETs, cognitive radio networks have emerged as a promising solution. These networks offer the potential to dynamically access available radio spectrum opportunistically, thereby alleviating spectrum starvation. Building upon these motivations, this section aims to introduce and discuss the main challenges faced by the integration of cognitive radio networks and VANETs. Additionally, we will explore the approaches and solutions designed to tackle these challenges, which will be further elaborated in the subsequent sections. By addressing these challenges individually, we can pave the way for more efficient and effective cognitive radio VANET.

### 2.1. Cognitive Radio Network

Cognitive radio networks are designed to address the issue of spectrum scarcity by intelligently identifying and utilizing available free spectrum in an opportunistic manner. The main goal is to ensure efficient utilization of the radio frequency spectrum, which is a finite and valuable resource for wireless communication. To achieve this, spectrum management techniques are employed within cognitive radio networks. These techniques are responsible for detecting the availability of unused or underutilized spectrum bands, which are referred to as "white spaces." The process of detecting and accessing these white spaces is crucial for cognitive radio devices to operate without causing harmful interference to the existing licensed (primary) users.

The coordination of operations within cognitive radio networks is multifaceted and depends on various factors. Security is a critical aspect, as cognitive radio devices need to ensure that they are accessing authorized spectrum bands and not interfering with licensed users. Therefore, protocols and mechanisms for secure spectrum sensing and authentication are implemented to protect against unauthorized access. Additionally, cognitive radio networks employ cross-layer design principles, allowing different layers of the network protocol stack to exchange information and make coordinated decisions. This integration enables efficient spectrum allocation, better adaptation to varying environmental conditions, and improved overall network performance.The Medium Access Control (MAC) layer also plays a crucial role in cognitive radio networks. It governs how devices access the shared spectrum efficiently while avoiding collisions and contention.

Dynamic spectrum access mechanisms at the MAC layer enable cognitive radios to opportunistically access available spectrum and quickly adapt to changes in the radio environment. Detailed approaches and challenges towards achieving overall spectrum efficiency are thoroughly discussed in the subsequent subsections.

#### 2.1.1. Availability of an Idle Channel

Detecting the availability of a channel is a crucial process in cognitive radio networks, as it enables cognitive radios to identify unused or underutilized spectrum bands, known as "white spaces," for opportunistic transmission. The efficient detection of available channels is fundamental to cognitive radio's ability to coexist with primary users and avoid causing harmful interference.

There are several methods commonly used for channel availability detection in cognitive radio networks:

1. Spectrum Sensing: Spectrum sensing involves the cognitive radio devices actively monitoring the radio frequency spectrum to detect the presence or absence of primary user transmissions. The cognitive radios use various sensing techniques such as energy detection, matched filter detection, and cyclostationary feature detection to sense the spectrum. By analyzing the received signal power and characteristics, the cognitive radios can identify free spectrum bands that can be used without causing interference to primary users.
2. Geo-location Database: In some cognitive radio systems, a centralized geo-location database is used to maintain information about the available spectrum bands in a specific geographical area. The database collects and updates the spectrum occupancy information from licensed users and other authorized sources. Cognitive radios query this database to determine the available channels for opportunistic usage.
3. Beacons: Beacons are signals transmitted by cognitive radios on specific channels to announce their presence and availability. These beacons can carry information about the cognitive radio's capabilities, spectrum requirements, and the channels they are currently using. Other cognitive radios in the vicinity can detect these beacons and assess the availability of channels for their own transmission.

#### 2.1.1.1. Spectrum Sensing:

Spectrum sensing is a fundamental process in cognitive radio networks that involves detecting the presence of available channels in the radio frequency spectrum. When a cognitive radio device seeks to access the spectrum for communication, it performs spectrum sensing to identify whether a channel is vacant and if it meets the specific constraints required for its transmission. If the channel is found to be available and suitable, the secondary user can occupy the respective channel for its communication needs. One of the advantages of spectrum sensing in cognitive radio networks is its independence from a centralized database connection. Unlike geo-location databases, which require constant updates and maintenance, spectrum sensing allows cognitive radios to autonomously sense the spectrum and detect available channels without relying on external information. However, one of the challenges faced by spectrum sensing is reducing false alarms caused by interference from other users or environmental factors. False alarms can lead to inefficient spectrum utilization and unnecessary contention, which may degrade the overall performance of cognitive radio networks.

There are two main methods for performing spectrum sensing in cognitive radio networks: energy detection and feature detection. Energy detection involves measuring the power levels in the frequency bands of interest to determine the presence or absence of primary user transmissions. Feature detection, on the other hand, looks for specific characteristics or patterns in the received signal to identify primary user activity. Recent advances in spectrum sensing research, as discussed in [6], include techniques such as constant false alarm rate detectors, blind detection, multiband sensing, wideband spectrum sensing, compressive sensing, and cooperative spectrum sensing. These advancements address the challenges of improving the accuracy and efficiency of spectrum sensing in cognitive radio networks.

To mitigate interference impact on spectrum sensing [5] propose an Efficient Recovery Control Channel design. This approach allows secondary users to establish new control channels among neighbors efficiently in response to changes in primary user activity, thereby minimizing primary user interference. Spectrum sensing offers the significant advantage of detecting available channels without relying on a database connection, making it a practical deployment option for cognitive radio networks. With ongoing research efforts aimed at resolving interference issues and enhancing spectrum sensing efficiency through improved features and algorithms, spectrum sensing holds great potential for further advancing the integration and performance of cognitive radio networks.

#### 2.1.1.1. Beacons:

Beacons play a vital role in cognitive radio networks as they serve as signals that inform other devices about the availability of specific channels. When a cognitive radio device intends to utilize a channel, it broadcasts a beacon signal to indicate its presence and interest in accessing that particular spectrum band.

The transmission of these beacons requires sufficient radio frequency output power to ensure their propagation to other devices in the vicinity. While beacons enable the sharing of information regarding spectrum availability, they do have certain drawbacks. One primary concern is the increase in frequency resources and additional interference sources introduced by the transmission of beacon signals. This can lead to reduced spectrum efficiency, making it essential to carefully manage and optimize beacon transmission strategies.

Despite these challenges, beacons find practical applications in cognitive radio networks. In the work of [4] researchers proposed an energy-efficient structure for beacon signal transmission in cognitive radio systems by synchronizing with index and payload information. This approach aims to minimize energy consumption while ensuring effective communication. In [6] beacons were used to study the impact of interference caused by secondary users due to misdetection and capacity outage of primary users in cognitive radio networks. By analysing such scenarios, researchers can develop strategies to mitigate interference and improve overall system performance.

Moreover, beacons have proven valuable in various applications , explored the use of beacons in a video-based overtaking assistant, where information from beacons on the position, speed, and direction of vehicles facilitated early detection of oncoming traffic, ensuring timely warnings to drivers. In [7], a time-based threshold policy for the collective protection of primary users was proposed using coordinated primary and secondary user communication based on beacon information. This approach enables the sharing of available spectrum opportunities and enhances coexistence between users under various backoff settings.

#### 2.1.1.3. Geo-location Database:

A geo-location database is an essential component of cognitive radio networks used to determine the availability of spectrum in specific locations, ensuring the smooth operation of the network. Once a cognitive radio device accesses the database, it can query the database to determine the available channels for communication. Unlike spectrum sensing or beacons, which require real-time sensing or broadcasting, the geo-location database provides users with insights into channel availability upon request. The advantage of a geo-location database lies in its ability to offer information about available spectrum in a particular geographical area without the need for continuous spectrum sensing or frequent beacon transmissions. This approach can be particularly useful in cases where real-time spectrum sensing is not practical or when a cognitive radio device needs to plan its communication in advance.

However, the effectiveness of a geo-location database depends on the accuracy and reliability of the information it contains. Ensuring the database is regularly updated and contains reliable data about available spectrum bands is crucial for successful spectrum allocation and utilization in cognitive radio networks. In two existing approaches for television white spaces, FCC and ECC, are evaluated. ECC focuses on protection-oriented policies, while FCC emphasizes extensive reuse of spectrum holes. Both approaches highlight the importance of small coverage areas for secondary networks, as this results in significantly increased spectrum efficiency. Geo-location database information can also be utilized for routing purposes, as demonstrated in [4]. They propose a distributed routing protocol where path selections and resource allocations are determined by receivers on a per-packet and per-hop basis. This framework efficiently adapts to spectrum dynamics and node mobility.

Additionally, works of [7] presents a geo-location database with detailed calculations to derive location-specific maximum permitted emission levels for white space devices (WSDs) operating in Digital Terrestrial Television bands. While a geo-location database offers significant advantages in spectrum allocation, its widespread deployment requires significant effort and cost. Despite this, the usage of geo-location databases marks a significant step forward in cognitive radio networks, provided that access to and usage of the database are permissible and well-regulated.

### 2.2. Network Selection in VANET

In recent years, significant progress has been made in vehicular networks, allowing for the advancement of Vehicular Ad Hoc Networks (VANETs) and enabling vehicles to share safety information. This capability plays a crucial role in reducing the probability of collisions and enhancing road safety. To support intelligent transportation system applications and facilitate the exchange of safety information among users, VANETs can be implemented using various network technologies. Some of the commonly considered networks for VANETs include Wireless Fidelity (WiFi) IEEE 802.11p, Wireless Access in Vehicular Environments (WAVE), IEEE 1609 WAVE, Worldwide Interoperability for Microwave Access (WiMAX) IEEE 802.16, Bluetooth, Infrared, and ZigBee. Among these, IEEE 802.11p stands out as a prominent standard that defines advancements within the IEEE 802.11 family specifically tailored for vehicular applications.

IEEE 802.11p standard primarily focuses on Layers 3 and 4 of the Open System Interconnection (OSI) model, encompassing elements such as Internet Protocol (IP), User Datagram Protocol (UDP), and Transmission Control Protocol (TCP). Additionally, it addresses management and data services within WAVE devices.

The deployment of VANETs with IEEE 802.11p is made possible through field operational tests, as demonstrated in [8]. Several research efforts have aimed to enhance the efficiency of VANET applications by implementing IEEE 802.11p. The resources on Roadside Units (RSUs) are scheduled collectively, and buses are utilized as moving infrastructure points to reduce the burden on RSUs. Mechanisms like Variable-Length Contention Free Period for MAC and Time-To-Live values are employed to ensure data credibility on buses.

Enhanced Distributed Channel Access (EDCA) in [7], introduces the transmission of acknowledgments for successfully received access categorized broadcast data frames, enabling the transmitter to evaluate the necessity for retransmission based on received feedback. An Arbitration Inter Frame Space Number parameter is also implemented for different access categories, adhering to strict policies for access based on the suggested framework. To increase contention levels and reduce information dissemination delay, a geocasting packet transmission technique for IEEE 802.11p is proposed in [8]. The quality of IEEE 802.11p based on extensive field testing campaigns, taking into account factors such as streets' layout, urban environment, traffic density, presence of heavy vehicles, trees, and terrain elevation, which impact the performance of urban RSUs.

Further research explores the integration of Proxy Mobile IPv6 (PMIPv6) and ETSI TC ITS Geo-Networking (GN) protocols to provide Internet access for VANETs in [9]. Performance evaluations for packet delivery ratio, delay, handover, and overhead demonstrate the feasibility of this design for deployment.Regarding the physical (PHY) and medium access control (MAC) layer improvements for vehicular applications, IEEE 802.11a-, IEEE 802.11b-, and IEEE 802.11g-based VANETs are evaluated in [10]. The results highlight that IEEE 802.11a- and g-based VANETs achieve better stability and throughput within certain distances, while IEEE 802.11b-based VANETs are more suitable for long-distance communication.In multi-hop VANET scenarios, a novel adaptation of PMIPv6 is introduced in [11], to ensure efficient network mobility management. This emphasizes the importance of network selection in VANETs in determining transmission efficiency and overall performance.

### 2.3. Routing in VANET

Path selection is a critical process in VANETs that directly influences the reliability and efficiency of information dissemination. In a study conducted by authors in[12], various existing position-based routing protocols are examined, with a focus on their applicability in different vehicular network environments. The researchers classify these protocols into three categories: vehicular network environment, topology-based protocols, and position-based protocols. By understanding the strengths and limitations of each type of routing protocol, it becomes easier to select the most suitable one for specific VANET scenarios.

One of the proposed routing methodologies, as suggested in [12], involves utilizing information obtained from mobility models to enhance path duration. The practical routing algorithms use this mobility information to make informed decisions. For instance, in areas with high vehicle density, packets are routed over the oldest links created by vehicles moving in the same direction. This approach aims to establish more stable paths in such congested regions. On the other hand, in areas with lower vehicle density, routing decisions are based on the most recent links created by vehicles moving in both directions, adapting to the sparse vehicular presence and ensuring effective communication.

Another approach, as presented in [13], is to employ a geographic stateless routing combined with node location and digital map data. This method is designed to provide a high packet delivery ratio with comparable latency when compared to other geographic routing schemes. By leveraging node locations and digital maps, the routing protocol can make better decisions regarding the optimal paths for data transmission. In [14] authors propose a routing protocol that calculates the reliability scores for each street edge using passive mechanisms. This allows the protocol to select the most reliable route for information dissemination. In [16] authors, enhance routing performance in one-way-multi-lane scenarios by enabling each candidate to self-determine its own priority using node degree, expected transmission count, and link lifetime. This self-adaptive mechanism ensures that the most suitable routes are chosen, leading to increased packet delivery ratio and throughput.

In the context of real-time video transmission over urban multi-hop VANETs, Asefi et all [17] , introduce an application-centric routing framework. This framework aims to facilitate video frame distortion and reduce streaming start-up delays, ensuring a smooth and reliable video transmission experience. In scenarios with varying VANET densities, queuing techniques based on mobility models, spatial traffic distribution, and the probability of connectivity can be employed to manage packet flows effectively. Moreover, considering multi-path routing, where multiple alternative paths are used simultaneously, could offer benefits in terms of load balancing, fault tolerance, and overall network performance.

**2.4.** Security in Cognitive Radio based VANET

Cognitive radio networks are susceptible to various security threats due to the dynamic nature of their users' mobility and the open nature of communication. The mobility of devices in cognitive radio networks makes it challenging to maintain consistent security measures, as users may access different parts of the network with varying characteristics and security levels. Additionally, the open communication framework allows users to access and utilize the available spectrum opportunistically, which can be exploited by malicious entities.

To enhance security and safeguard against potential attacks, a centralized security approach can be adopted in cognitive radio networks. This approach involves implementing centralized security mechanisms and protocols that can efficiently monitor and control network access, ensuring that only authorized users are allowed to access the available spectrum. By centralizing security, it becomes possible to detect and respond to security threats more effectively.

Authors in [18], delve into the different types of security breaches and attacks that can occur in cognitive radio mobile ad hoc networks. In response to Spectrum Sensing Data Falsification attacks, they propose a novel bio-inspired consensus-based cooperative spectrum sensing scheme. This scheme aims to improve the accuracy and reliability of spectrum sensing by leveraging cooperative behavior among secondary users.

Furthermore, to enhance user authentication and protect user identities, an authentication scheme using identity-based cryptography with threshold secret sharing is suggested. This approach ensures that only authorized users can access the network, enhancing the overall security of cognitive radio networks.

Moving on to the domain of Vehicular Ad hoc Networks (VANETs), security becomes a paramount concern, as information sharing occurs among unknown users on the road. The safety of VANETs relies heavily on secure and reliable communication between vehicles. Other works also emphasizes on a ring signature technique for an efficient multi-level conditional privacy preservation authentication protocol in VANETs. This technique allows for conditional privacy preservation while maintaining authentication standards. However, it should be noted that the use of ring signatures may introduce communication overhead proportional to the number of ring members, which should be carefully managed.

To address communication overhead concerns, the SMART protocol for VANETs, employs data aggregation and message fragmentation techniques to achieve efficient bandwidth usage. By reducing unnecessary data transmission and optimizing message delivery, the SMART protocol ensures a more efficient and reliable communication process in VANETs.

## III. OPEN ISSUES AND CHALLENGES

Designing cognitive radio networks in Vehicular Ad hoc Networks (VANETs) presents various open issues and research directions. The work in [9], address several key challenges and features of cognitive radio networks in VANETs, including spectrum sensing, radio operation policies, physical limitations, database configuration, radio self-configuration, adaptive algorithms, and security issues. Similarly, Di Felice et all. In [19] discuss additional characteristics like integration with spectrum databases, mobility impact, cooperation roles, and the importance of a common control channel in cognitive radio VANETs. Challenges specific to vehicular communication, based on IEEE 802.11, such as vehicular speed, distance, handover and mobility management, and unique multi-hop inter-vehicular communication, are also highlighted in [20]. This section will delve into these open issues and research directions in detail.

3.1. Coordination between Licensed and Unlicensed Users: A major challenge in deploying cognitive radio networks among VANET vehicles is ensuring smooth coordination between licensed network users (primary users) and unlicensed users (secondary users). Secondary users must not disrupt the primary users' operations while accessing the spectrum opportunistically. Efficient operation among cognitive users can be achieved by enabling licensees to implement cognitive radio networks internally within their own network, thus increasing overall radio network efficiency. Secondary users can utilize multiple licensed services through proper scheduling, and mutual interference can be avoided with efficient coordination mechanisms.

3.2. Duration of Spectrum Opportunities: The random switching of spectrum bands can significantly impact communication performance. Therefore, a vehicle user should be able to select a spectrum band that offers the best connectivity for the longest time frame. To achieve this, a database can be established in each cluster to maintain real-time information about available spectrums. With the database's application, secondary users can evaluate and select the best spectrum with the longest duration for establishing connections, ensuring efficient spectrum utilization and communication.

3.3. Random Movements of Vehicles: Vehicles in VANETs exhibit random movements, making it unlikely for a vehicle to stay in the same location for an extended period. Spectrum usage duration is generally short, leading to frequent spectrum switching. This dynamic nature of VANETs poses challenges in implementing cognitive radio networks. VANET users must rapidly detect the best available spectrum and establish connections before vehicles move out of their current clusters. Efficient handover mechanisms need to be developed to ensure smooth communication transitions as vehicles change their positions, making handover schemes a promising research direction to ensure the viability of cognitive radio networks in VANETs.

3.4. Multiple Points of Observation: Cognitive radio networks in VANETs offer multiple points of spectrum observation for users. However, uncertainties in the outdoor environment, with clusters located close to each other, raise the possibility of interference and false alarms. This can lead to the incorrect selection of non-idle spectrums due to false data. To mitigate these false alarms, a framework ensuring the reliability of data dissemination on each spectrum should be designed. Proper selection mechanisms based on current cognitive radio network conditions and VANET user locations need to be integrated to ensure the efficiency and feasibility of cognitive radio networks in VANETs.

3.5. Interference: Interference between primary and secondary users is a significant challenge in cognitive radio networks. CoCast, a multi-channel, multi-radio multi-cast protocol proposed in [21], addresses interference issues among Wi-Fi users and inter-vehicle users by employing parallel frame transmission over orthogonal frequency division multiplexing (OFDM) sub-channels and network coding to exploit spectral diversity. Research should focus on designing efficient frameworks, to minimize interference, enabling secondary users to transmit without disturbing primary users' communication processes, especially considering the random movements of vehicles in VANETs.

3.6. Delay: VANETs are designed to ensure timely transmission of safety messages to minimize collisions and enhance road safety. As such, delay constraints become crucial, especially in VANET applications. Cognitive radio networks must allocate spectrum and share it under specified delay constraints. This requires the employment of suitable frameworks, possibly leveraging the geo-location of VANET vehicles to minimize transmission delays through proper spectrum allocation based on their locations.

3.7. Security: In cognitive radio VANETs, vehicles connect randomly to available spectrums and communicate with each other. This setup creates vulnerabilities, making primary and secondary users susceptible to malicious attacks such as DoS and jamming. To ensure the feasibility of cognitive radio VANET deployment in real-time scenarios, effective detection and prevention mechanisms must be developed to safeguard users against such attacks.

In addition to the previously mentioned research challenges, there are several other important issues that researchers need to address to successfully deploy Cognitive Radio (CR) based VANETs. These challenges include:

- QoS Provisioning: Ensuring Quality of Service (QoS) in CR-based VANETs is crucial, especially for safety-critical applications. Researchers must develop QoS-aware cognitive radio algorithms that can dynamically allocate and prioritize spectrum resources based on application requirements and network conditions.
- Channel Estimation and Prediction: Accurate channel estimation and prediction are essential for efficient spectrum sensing and access in CR-based VANETs. Developing reliable channel estimation techniques that consider the highly dynamic vehicular environment is a significant challenge.
- Spectrum Mobility and Handoff Management: Vehicles in VANETs experience frequent mobility, which may require them to switch to different spectrum bands. Effective spectrum mobility and handoff management techniques are needed to minimize communication disruptions during transitions.
- Spectrum Sharing with Infrastructure-based Networks: CR-based VANETs often coexist with infrastructure-based wireless networks (e.g., cellular networks, Wi-Fi networks). Efficient spectrum sharing mechanisms between VANETs and infrastructure networks need to be designed to avoid harmful interference and ensure fair spectrum access for all users.
- Spectrum Etiquette and Cooperation: Cooperative spectrum sharing among vehicles is crucial to enhance spectrum efficiency. Developing spectrum etiquette protocols that encourage vehicles to cooperate in spectrum access and sharing is essential to achieve optimal spectrum utilization.
- Real-time Decision Making: CR-based VANETs require fast and real-time decision-making capabilities to respond quickly to changing spectrum availability and mobility patterns. Developing efficient algorithms and protocols that can make rapid decisions without sacrificing accuracy is a challenging task.
- Energy Efficiency: Energy consumption is a critical concern for vehicles in VANETs. Cognitive radio algorithms must be designed to optimize spectrum access decisions while considering the energy constraints of the vehicles.
- Scalability: As the number of vehicles in a VANET increases, the cognitive radio network must be scalable to accommodate the growing demand for spectrum resources. Designing scalable CR-based VANET architectures is essential for future large-scale deployments.
- Interference Management in Dense Environments: In dense urban environments, the presence of numerous vehicles can lead to high levels of interference. Effective interference management techniques, such as interference cancellation and power control, are required to maintain reliable communication in such scenarios.
- Cooperative Spectrum Sensing Reliability: Cooperative spectrum sensing relies on information gathered from multiple vehicles. Ensuring the reliability of this information and mitigating the effects of malicious or faulty reporting is critical for the success of CR-based VANETs.
- Dynamic Spectrum Access Policies: Developing dynamic spectrum access policies that can adapt to the changing network conditions and regulatory requirements is a challenging task. These policies must be flexible enough to accommodate various types of applications and services.
- Cross-Layer Optimization: CR-based VANETs involve interactions between different layers of the communication protocol stack. Cross-layer optimization approaches are required to enhance overall network performance by jointly considering factors from multiple layers.

The deployment of CR-based VANETs introduces several research challenges that need to be addressed to realize their full potential. Researchers must focus on QoS provisioning, accurate channel estimation, spectrum mobility, cooperation, real-time decision-making, energy efficiency, scalability, interference management, cooperative spectrum sensing reliability, dynamic spectrum access policies, and cross-layer optimization to enable efficient, reliable, and secure communication in CR-based VANETs.

## IV. PERFORMANCE METRICS

Performance metrics play a crucial role in evaluating the effectiveness and efficiency of cognitive radio VANETs. These metrics provide insights into various aspects of the network's performance, enabling researchers and engineers to identify strengths and weaknesses and make informed decisions for improvements. Here is a list of common performance metrics used in cognitive radio VANET evaluations:

- Throughput: Throughput measures the average number of packets successfully transmitted per second. It indicates the capacity of the network to handle data traffic efficiently.
- End-to-End Delay: End-to-end delay quantifies the time it takes for a packet to travel from the source node to the destination node. Low end-to-end delay is crucial for real-time applications and critical safety messages.
- Transmission Overhead: Transmission overhead represents the additional time or data used for packet transmission beyond the actual payload. Lower transmission overhead indicates more efficient use of resources.
- Number of Messages per Node: This metric measures the number of messages received and sent by individual nodes, reflecting their communication load.
- Minimum Number of Hops: The minimum number of hops measures the shortest path (in terms of intermediate nodes) a packet takes from source to destination. Minimizing the number of hops enhances communication efficiency.
- Beacon Interval: Beacon interval refers to the time between consecutive beacon transmissions. Beacons are essential for coordination and synchronization in VANETs.
- Beacons per Second: Beacons per second measure the frequency of beacon transmissions over a period, indicating how often vehicles exchange vital information.
- Density Estimation: Density estimation predicts or estimates the node density in a specific area. Understanding node density helps optimize resource allocation and communication strategies.
- Forwards per Route: This metric counts the number of times a packet is forwarded along its route, indicating the efficiency of data forwarding in the network.
- Warning Notification Time: Warning notification time measures how long it takes to notify or warn a user about an event or critical information. Short notification times are essential for timely responses in safety-critical scenarios.
- Path Duration: Path duration measures the time taken to route a packet from source to destination, providing insights into communication latency.
- Packet Success Rate: Packet success rate measures the percentage of packets that are successfully transmitted for every attempt. A high success rate signifies reliable communication.
- Spectrum/Bandwidth Utilization: Spectrum or bandwidth utilization measures the percentage of spectrum or bandwidth used on average, indicating how effectively the available resources are utilized.
- Computational Time: Computational time assesses the complexity of the algorithms used in the cognitive radio network. Lower computational time is desirable for efficient decision-making and resource allocation.

These performance metrics help researchers and network operators evaluate the performance of cognitive radio VANETs under different scenarios and identify potential areas for improvement. By optimizing these metrics, cognitive radio VANETs can achieve better communication reliability, lower latency, and improved overall network efficiency.

## V. CONCLUSION

The research work on cognitive radio VANET has made significant progress, but practical challenges still persist. The highlighted problems, such as coordination, duration of spectrum opportunities, interference, and security, are critical concerns that need to be addressed. Moreover, the current static nature of cognitive radio VANET limits its efficiency in dynamic environments with fluctuating interference, high mobility, and security threats. To ensure the practicality of cognitive radio VANET, an integrated model is being developed to address these challenges. This model incorporates a proper database that considers parameters like vehicle locations, power model, and signal-to-noise ratio for efficient spectrum allocation. The make-before-break concept will minimize delays during spectrum handover. Addressing these issues and developing an adaptive framework will enhance the applicability and efficiency of cognitive radio VANET, making it a viable solution for future vehicular communication systems. Continued research and development efforts are essential to overcome the remaining obstacles and unleash the full potential of cognitive radio VANET.

## REFERENCES


[1] Al-Sultan S, Al-Doori MM, Al-Bayatti AH, Zedan H. A comprehensive survey on vehicular ad hoc network. Journal of network and computer applications. 2014 Jan 1;37:380-92. .

[2] Raya M, Hubaux JP. Securing vehicular ad hoc networks. Journal of computer security. 2007 Jan 1;15(1):39-68.

[3] Chembe C, Noor RM, Ahmedy I, Oche M, Kunda D, Liu CH. Spectrum sensing in cognitive vehicular network: State-of-Art, challenges and open issues. Computer Communications. 2017 Jan 1;97:15-30.

[4] Singh KD, Rawat P, Bonnin JM. Cognitive radio for vehicular ad hoc networks (CR-VANETs): approaches and challenges. EURASIP journal on wireless communications and networking. 2014 Dec;2014(1):1-22.

[5] Joy EC, Zhang S, Liu E, Theresa EE, Elias EC. Cognitive radio aided vehicular ad-hoc networks with efficient spectrum allocation and QoS guarantee. In2016 22nd International Conference on Automation and Computing (ICAC) 2016 Sep 7 (pp. 156-161). IEEE.

[6] Di Felice M, Doost-Mohammady R, Chowdhury KR, Bononi L. Smart radios for smart vehicles: Cognitive vehicular networks. IEEE Vehicular Technology Magazine. 2012 May 17;7(2):26-33.

[7] Liang YC, Chen KC, Li GY, Mahonen P. Cognitive radio networking and communications: An overview. IEEE transactions on vehicular technology. 2011 Jun 6;60(7):3386-407.

[8] Kim W, Gerla M, Oh SY, Lee K, Kassler A. CoRoute: A new cognitive anypath vehicular routing protocol. Wireless Communications and Mobile Computing. 2011 Dec;11(12):1588-602.

[9] Lim JM, Chang YC, Alias MY, Loo J. Cognitive radio network in vehicular ad hoc network (VANET): A survey. Cogent engineering. 2016 Dec 31;3(1):1191114.

[10] Salameh HB, Krunz M, Younis O. MAC protocol for opportunistic cognitive radio networks with soft guarantees. IEEE transactions on mobile computing. 2009 Jan 19;8(10):1339-52.

[11] Asefi M, Céspedes S, Shen X, Mark JW. A seamless quality-driven multi-hop data delivery scheme for video streaming in urban VANET scenarios. In2011 IEEE International Conference on Communications (ICC) 2011 Jun 5 (pp. 1-5). IEEE.

[12] Fonseca A, Camoes A, Vazao T. Geographical routing implementation in NS3. InProceedings of the 5th International ICST Conference on Simulation Tools and Techniques 2012 Mar 19 (pp. 353-358).

[13] Xiang Y, Liu Z, Liu R, Sun W, Wang W. GeoSVR: A map-based stateless VANET routing. Ad Hoc Networks. 2013 Sep 1;11(7):2125-35.

[14] Bernsen J, Manivannan D. RIVER: A reliable inter-vehicular routing protocol for vehicular ad hoc networks. Computer Networks. 2012 Nov 30;56(17):3795-807.

[15] Mohammed MA, Al-Daraiseh AA. Toward secure vehicular ad hoc network: a survey. IETE Technical Review. 2014;29:80-9.

[16] Lim JM, Chang YC, Alias MY, Loo J. Cognitive radio network in vehicular ad hoc network (VANET): A survey. Cogent engineering. 2016 Dec 31;3(1):1191114.

[17] Asefi M, Mark JW, Shen X. An application-centric inter-vehicle routing protocol for video streaming over multi-hop urban VANETs. In2011 IEEE International Conference on Communications (ICC) 2011 Jun 5 (pp. 1-5). IEEE.

[18] Zhang L, Ding G, Wu Q, Zou Y, Han Z, Wang J. Byzantine attack and defense in cognitive radio networks: A survey. IEEE Communications Surveys & Tutorials. 2015 Apr 13;17(3):1342-63.

[19] Di Felice M, Doost-Mohammady R, Chowdhury KR, Bononi L. Smart radios for smart vehicles: Cognitive vehicular networks. IEEE Vehicular Technology Magazine. 2012 May 17;7(2):26-33.

[20] Lim JM, Chang YC, Alias MY, Loo J. Cognitive radio network in vehicular ad hoc network (VANET): A survey. Cogent engineering. 2016 Dec 31;3(1):1191114.

[21] Bestak R, Kencl L, Li LE, Widmer J, Yin H, editors. NETWORKING 2012: 11th International IFIP TC 6 Networking Conference, Prague, Czech Republic, May 21-25, 2012, Proceedings, Part I. Springer; 2012 May 16.