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Spectrum Sensing in Cognitive Radio Networks Using 5G Technology

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Abstract: With rapid evolution in wireless communication technologies, Cognitive Radio Vehicular Networks (CR-VNs) have emerged and are being developed, by integrating cognitive radio techniques with vehicular networking systems, for better spectrum utilization and network performance. Besides that, 5G technologies can achieve their goal using CR-VNs with possible improvements in vehicular communication systems, higher data rates, low latency, and improved reliability in vehicular environments. This paper takes the idea of Cognitive Radio in Vehicular Networks using 5G technology through integration, benefits, challenges, and future developments which it may face. Then, the role of CR on dynamic spectrum management, spectrum sensing, and coexistence with other wireless technologies about vehicular networks, also what impact 5G can have on CR-VNs. Finally, identify areas of research that might make a difference in bringing about advancements in CR-VNs in the context of 5G.

Keywords: *Cognitive Radio, Vehicular Networks, 5G, Spectrum Management, Dynamic Spectrum Access, Communication Technologies, 5G Networks, Vehicle-to-Everything (V2X), Spectrum Sensing, 5G-enabled CR-VNs*

1. Introduction

CR, a novel application of Cognitive Radio to the vehicular networks, intends to mitigate the problem of spectrum scarcity in modern wireless communication systems. In various types of communications involved in V2V, V2I, and V2X communications in vehicular networks, safety, efficiency, and connectivity on roads are dependent upon reliable high-throughput, low-latency communication technologies. Current traditional mechanisms of spectrum allocation face huge challenges in fulfilling this demand, especially in highly dynamic environments such as vehicular networks.

A key enabling technology of Cognitive Radio is dynamically accessing unused portions of the spectrum for more efficient use. In view of its rollout with 5G, which promises ultra-high-speed data transmission, very low latency, and enormous connectivity, CR-VNs have all the chances of having significant importance in the intelligent transportation system and smart city environment of the future.

The paper presents a synergy between Cognitive Radio and 5G, wherein the benefits and challenges of vehicular networks are brought forth as mandatory for realizing the full potential of CR-VNs.

2. Cognitive Radio and Vehicular Networks: Concepts and Synergy

2.1 Cognitive Radio (CR)

This system will be an intelligent wireless communication system that can automatically discover the available channels in a spectrum and adapt its transmission parameters depending on the environment. Its key principles are the following:

- **Spectrum Sensing:** Identifying unused spectrum bands (spectrum holes) in the radio frequency (RF) spectrum.
- **Spectrum Management:** Allocating spectrum resources to users in a way that maximizes efficiency and minimizes interference.
- **Spectrum Sharing:** Enabling users to share the spectrum while avoiding harmful interference to primary users (licensed users).
- **Cognitive Engine:** A decision-making unit that facilitates the dynamic adaptation of the communication system based on real-time spectrum analysis.

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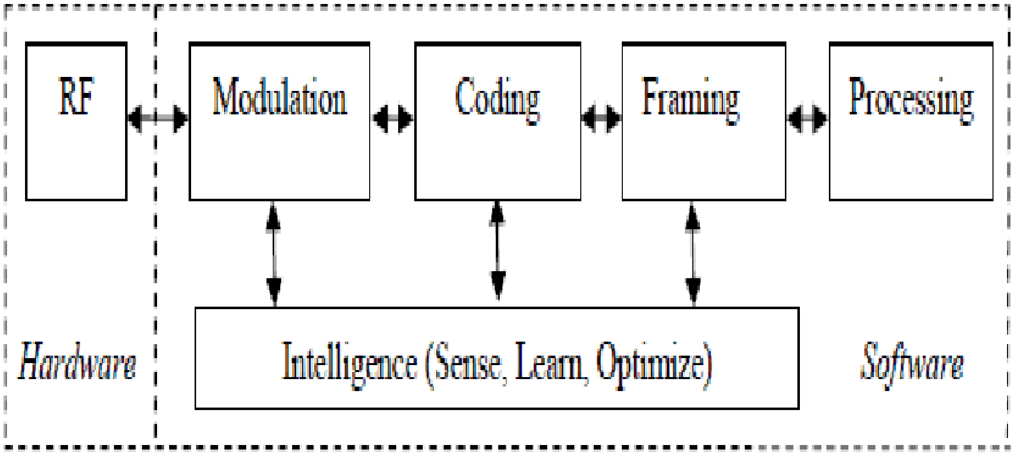

Fig 2.1 Block diagram of cognitive radio

2.2 Vehicular Networks and the Need for Efficient Spectrum Utilization

Vehicular networks, including V2V, V2I, and V2X communication, form the backbone of the modern intelligent transportation ecosystem. These networks enable vehicles to communicate with each other and surrounding infrastructure, facilitating a range of applications, such as:

- **Safety Applications:** Collision avoidance, emergency braking, and real-time traffic alerts.
- **Infotainment:** Streaming media, social media updates, and real-time content delivery.
- **Autonomous Driving:** Data exchange for vehicle autonomy, including sensor fusion, lane-keeping, and obstacle detection.

However, with such data-intensive applications as HD video streaming, real-time traffic monitoring, and self-driving cars, the spectrum became congested. It was not possible for traditional wireless technologies to ensure desired Quality of Service (QoS) mainly because there was limited availability of the spectrum and increased interference caused by other wireless networks.

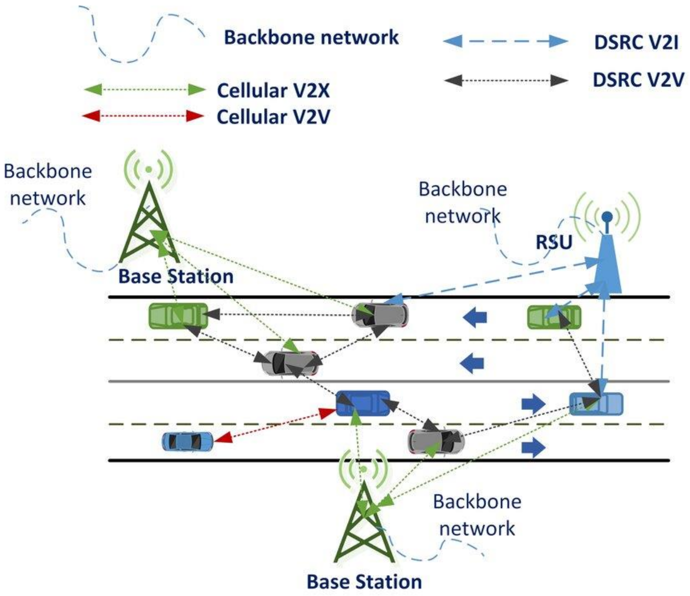

Fig2.2 Overview of Vehicular network

3. The Role of 5G in Cognitive Radio Vehicular Networks

5G technology introduces several key features that significantly enhance the capabilities of CR-VNs:

3.1 Ultra-Reliable Low Latency Communication (URLLC)

Thus, in a scenario like vehicular networks where the applications within this environment are safety-critical (collision avoidance and even the promise of autonomous driving that may depend on V2V real-time communications) - 5G ensures ultra-reliable, ultra-low latency communications. Again, Cognitive Radio might be useful to complement this scenario: enabling dynamic spectrum access that ensures vehicles at any moment find channels that are sufficiently low latency even in densified regions.

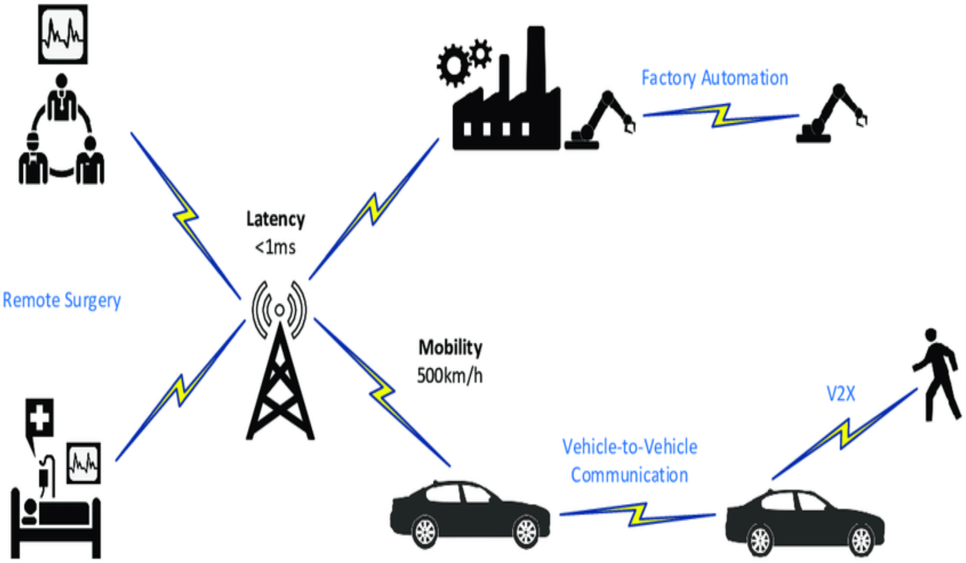

Fig 3.1 Ultra-Reliable Low Latency Communication

3.2 High Data Rates and Enhanced Mobile Broadband (eMBB)

5G supports the high rates of data transfer for an ultra-high bandwidth requirement from applications such as video streaming, remote diagnostics, or cloud-based vehicular data exchange. In this area, CR technology of vehicular networks helps to optimize and reduce congestion through the significant data traffic of the face.

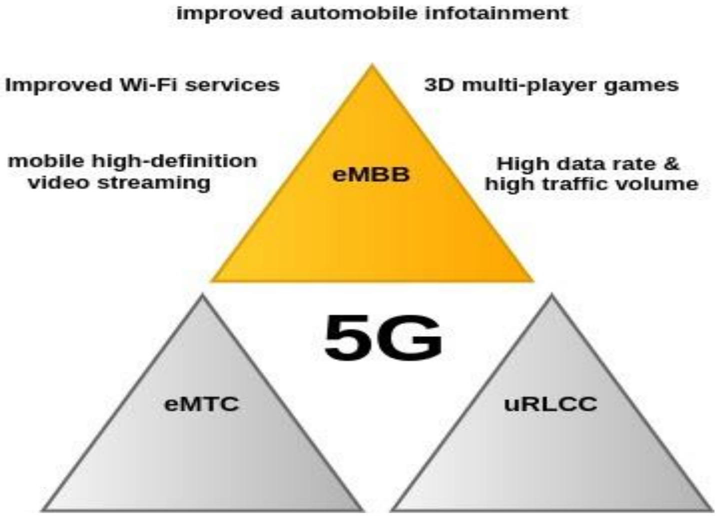

Fig 3.2 5G Enhanced Mobile Broadband

3.3 Massive Machine-Type Communications (mMTC)

It will have exponentially increasing numbers of connected devices and exponentially vast amounts of machine-to-machine (M2M) communications, which could encompass sensors, cameras, or other Internet of Things devices in a vehicular network. Cognitive Radio enables those devices to dynamically access the spectrum bands that are temporarily unused by the primary users, thus improving the overall efficiency of the network.

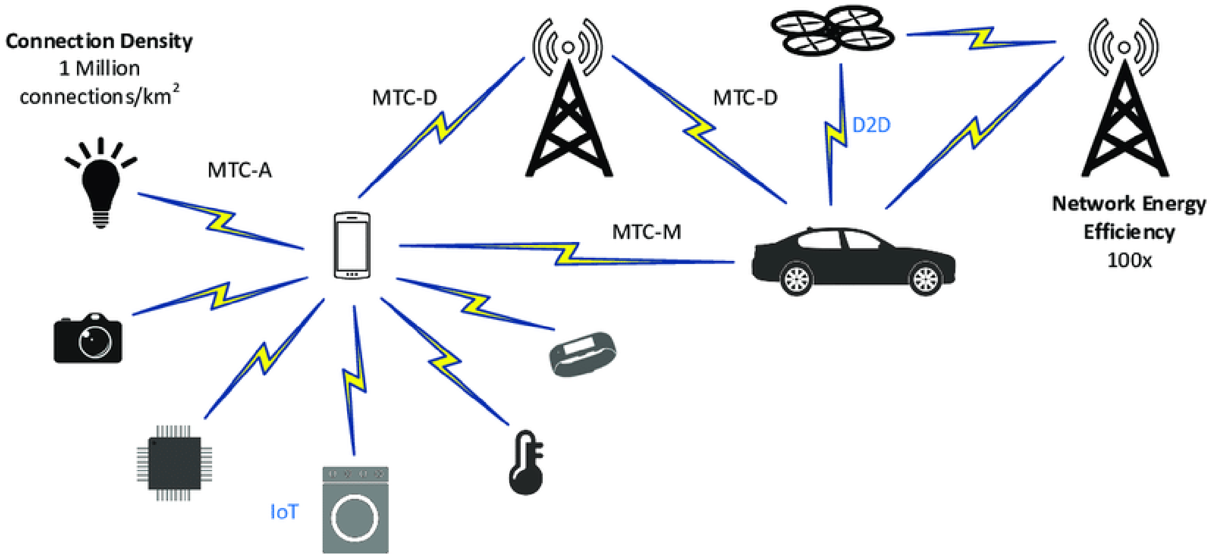

Fig 3.3 Massive Machine-Type Communications

4. Key Challenges in Integrating CR and 5G for Vehicular Networks

Despite the potential advantages, several challenges remain in integrating CR technology with 5G vehicular networks:

4.1 Spectrum Sensing and Interference Management

In order to have accurate and efficient unused spectrum detection, cognitive Radio systems must ensure high accuracy in sensing unused spectrum. This requirement is difficult to meet in dynamic vehicular environments because of the challenges posed by high mobility of vehicles, rapid changes in network conditions, and interference from other forms of communication. In addition to these requirements, interference management between CR-enabled vehicular networks and primary users, which are licensed networks, poses a significant challenge.

4.2 Scalability and Network Architecture

It is expected that with 5G vehicular networks, millions of connected devices, such as vehicles, sensors, and infrastructure components, will be supported. Therefore, the integration of CR requires a flexible and scalable network architecture that would manage the massive scale of V2X communications and ensure efficient allocation of spectrum resources.

4.3 Security and Privacy

Vehicular networks are vulnerable to security threats, including eavesdropping, spoofing, and denial-of-service attacks. The dynamic nature of CR-VNs, where vehicles rapidly switch channels, introduces additional security concerns. Ensuring secure and reliable communication in CR-enabled 5G vehicular networks is critical for the safety and privacy of users.

4.4 Standardization and Interoperability

The deployment of CR in 5G-enabled vehicular networks requires the development of global standards to ensure interoperability across different manufacturers and service providers. Achieving seamless communication between different vehicle types, infrastructure, and communication systems is a key challenge in the realization of CR-VNs.

5. Research Directions and Future Trends

5.1 Advanced Spectrum Sensing Techniques

Future research could focus on enhancing spectrum sensing techniques to improve accuracy and reduce false alarms in dynamic vehicular environments. Machine learning algorithms and deep learning models can play a significant role in predicting spectrum availability based on historical data and real-time network conditions.

5.2 Autonomous Spectrum Management

To fully exploit the potential of CR in vehicular networks, autonomous spectrum management algorithms need to be developed. These algorithms would enable vehicles to intelligently decide when and how to access spectrum resources, ensuring optimal performance without human intervention.

5.3 Integration with Edge Computing and Network Slicing

The integration of edge computing and network slicing with CR-VNs can enhance the efficiency and performance of 5G vehicular networks. Edge computing enables real-time data processing at the network's edge, reducing latency and bandwidth requirements. Network slicing allows for the creation of virtual networks tailored to specific vehicular applications, optimizing the use of spectrum resources.

5.4 Quantum Communication for CR-VNs

As quantum computing and communication technologies continue to develop, the use of quantum-based spectrum sensing and communication in CR-VNs could provide unprecedented performance improvements in terms of speed, security, and reliability.

6. Cognitive Radio for Dynamic spectrum management

Mental radio (CR) has been generally perceived as the vital innovation to empower DSA. A CR alludes to an insightful radio framework that can progressively and independently adjust its transmission systems, including transporter recurrence, band-width, communicate power, recieving wire pillar or regulation plan, and so on, in light of the between activity with the general climate and its consciousness of its interior states (e.g., equipment and programming models, range use strategy, client needs, and so on) to accomplish the best exhibition. Such reconfiguration capacity is acknowledged by programming characterized radio (SDR) processor with which the transmission systems is changed by computer programming. Additionally, CR is likewise worked with discernment which permits it to notice the climate through detecting, to investigate and handle the noticed data through learning, and to choose the best transmission procedure through thinking. Albeit a large portion of the current CR investigates to date have been zeroing in on the investigation and acknowledgment of mental capacity to work with the DSA, the very late exploration has been finished to investigate more potential innate in the CR technology by man-made brainpower (artificial intelligence). In view of the gathered data, it decides the best functional parameters to streamline its own exhibition subject to the insurance to the Discharge and afterward reconfigures its framework likewise. The data gathered over the long haul can likewise be utilized to investigate the radio climate, like the traffic measurements and channel blurring measurements, so the CR gadget can figure out how to perform better in future dynamic variation.

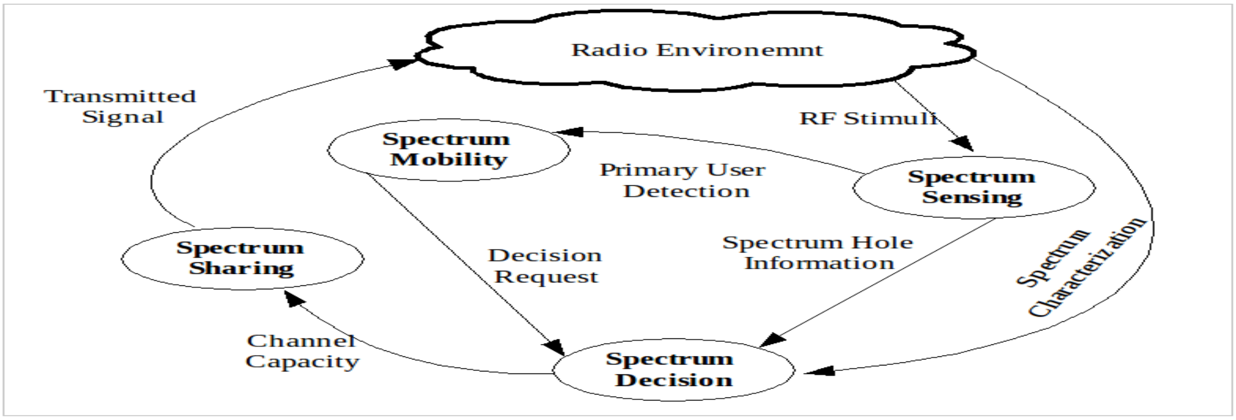

Fig6.1 Cognitive radio for dynamic spectrum management

7. Spectrum Sensing using Matched Filter Detection

Matched filter detector is a coherent pilot sensor that maximizes the *SNR* at the output of the detector. It is an optimal filter that requires the prior knowledge of the PU signals. This sensing technique is the best choice when some information about the PU signal are available at the SU receiver. Assuming that the PU transmitter sends a pilot stream simultaneously with the data, the SU receives the signal and the pilot stream. Matched filter detection is performed by projecting the received signal in the direction of the pilot, *xp*, as illustrated in Figure

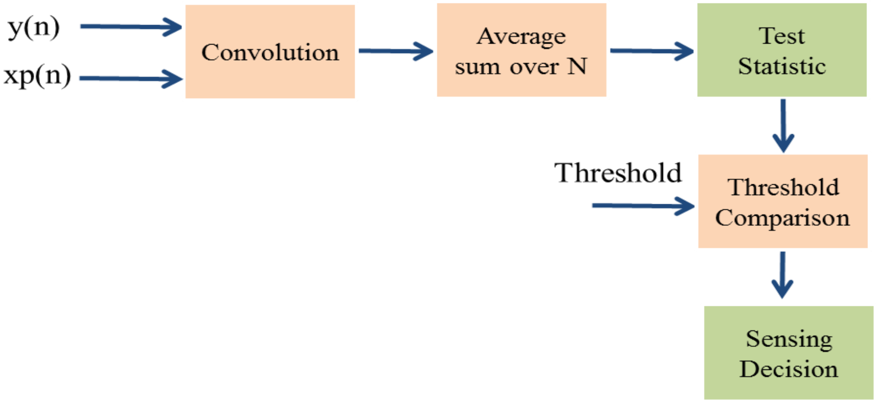

Fig.7.1 Matched filter detection

The test statistic is expressed as:

$$T_{MFD} = \sum_{N} y(n)\, x^{*}_{p}(n) \qquad \text{(i)}$$

Where xp denotes the PU signal, *y* denotes the SU received signal, and T_{MFD} denotes the test statistic of the matched filter detector. The test statistics, T_{MFD}, is then compared with a threshold in order to decide about the spectrum availability. The SU received signal, as well as the PU signal, are approximated to be random Gaussian variables. As a linear combination of Gaussian random variable, T_{MFD} is also approximated as a Gaussian random variable.

$$\left\{ \begin{array}{l} \text{If } T_{MFD} \geq \lambda, \text{ PU signal present} \\ If\ T_{MFD} < \lambda, \text{ PU signal absent} \end{array} \right. \qquad \text{(ii)}$$

Based on the Neyman-Pearson criteria, the probability of detection and the probability of falsealarm are given by

$$Pd = Q\left(\frac{\text{à}-E}{\sqrt{E\ \text{ả}}}\right), \qquad Pfd = Q\left(\frac{\text{à}}{\sqrt{\quad \text{ả}}}\right) \qquad \text{(iii)}$$

$E\text{â}^{\text{ã}}$

Where E is the PU signal energy, λ is the sensing threshold, $Q(.)$ is the Q- function, and $\delta^{=}$ is the noise variance. The sensing threshold is expressed as a function of the PU signal energy and noise variance. Expecting that the sign is totally known is outlandish and illogical. Some correspondence frameworks contain pilot stream or synchronization codes for channel assessment and recurrence band detecting. An original crossover matched channel structure is proposed in in light of conventional matched channel by blending fragmented and equal matched channel to defeat the recurrence offset responsiveness. This new design permits adjusting between the detecting time and the equipment intricacy. As both transporter recurrence offset (CFC) and stage clamor (NP) disparage the detecting execution of matched channel discovery, matched channel identification execution is analyzed within the sight of CFC and PN in Powerful detecting procedure is proposed to beat the adverse consequence of CFC and NP on the exhibition and the capacity of the detecting.

Then again, the detecting edge for matched channel identifier is a significant boundary with respect to the next detecting procedures where various scientists treated the limit determination. In the coordinated channel identification has been utilized with a static worth to figure the range inhabitance out. In each sets of (Pd, Pf) is related with a specific limit to pursue detecting choice. In other examination works, the detecting edge is resolved powerfully by duplicating the hypothetical limit by a positive element . Others don't make reference to how the edge was chosen. Consequently, with a static edge, the detecting choice isn't solid due to the clamor vulnerability. Thusly, the exhibition of the matched channel put together identification depends principally with respect to the accessible data about the PU signal, including the transmission capacity, focal recurrence, and tweak conspire. The detecting execution debases when these information are wrong or questionable.

7.1 Evaluation Metrics

To evaluate the performance of the spectrum sensing techniques, a number of metrics have been proposed, including the probability of detection, P_d, the probability of false alarm, P_{fd}, and the probability of miss detection, P_{md}. P_d is the probability that the SU declares the presence of the PU signal when the spectrum is occupied . The probability of detection is expressed as:

P_d = Prob (H_1/H_1) (iv)

Where H0 and H_1 denote respectively the absence and the presence of the PU signal. The higher the P_d, the better the PU protection is.

The probability of false alarm, P_{fd}, is the probability that the SU declares the presence of the PU signal when the spectrum is actually free (idle). It is expressed as:

P_{fd} = Prob (H_1/H_0) (v)

The lower the P_{fd}, the more the spectrum access the SUs will obtain.

The probability of miss detection, P_{md}, is the probability that the SU declares the absence of a PU signal when the spectrum is occupied. It is given by

P_{md} = Prob (H_0/H_1) (vi)

These three metrics measure the efficiency of the spectrum sensing techniques and can be expressed as:

$P_d + P_{fd} + P_{md} = 1$ (vii)

There is a tradeoff between the likelihood of phony problem and the likelihood of miss discovery. Misleading location of the PU movement makes impedance the PU and missed identification of the PU action botches range valuable open doors. This tradeoff can be communicated as moderate with Pfd and forceful with Pmd; and a range detecting procedure needs to satisfy the limitations on the two probabilities .

8. Conclusion

The advent of 5G technologies in Cognitive Radio Vehicular Networks (CR-VNs) opens exciting prospects for improvements in efficiency, reliability, and performance in modern vehicular communication systems. Despite big challenges in integrating CR with 5G, the opportunities that emerge make interesting research areas such as the area of spectrum sensing, network management, and security issues. With such challenges attended to, CR-enabled 5G vehicular networks will be enablers of smart cities and automated transportation systems for better road safety, efficient traffic management, and an improved user experience. We described spectrum sensing techniques based on Matched Filter Detection,We also presented the different metrics used for performance evaluation.

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