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COMPREHENSIVE STUDY OF V2X AND SURVEY OF DEDICATED SHORT RANGE COMMUNICATION (DSRC) WITH ALGORITHMS, APPLICATIONS, BENEFITS AND LIMITATIONS

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Abstract

New directions and techniques are required in this subject due to the acceleration of technical development in the automotive industry and the extremely high complexity of applications for infrastructure and vehicles. Because of this, there is an excessive amount of study being done on the problem of how to make the automotive network traffic-friendly. Vehicle-to-Everything (V2X) communication is pivotal in advancing intelligent transportation systems by enabling real-time data exchange between vehicles, infrastructure, pedestrians, and networks. The first section of this paper focused on Dedicated Short Range Communication (DSRC), Wireless Access in Vehicular Environment (WAVE), and 802.11p standards and descriptions of some vehicular network applications, adding some simulations and real-world test examples, as well as discussing the results. Second section of this paper provides an in-depth review of the algorithms underpinning DSRC, encompassing medium access control, resource allocation, security protocols, and interoperability mechanisms. By analysing current methodologies and their performance metrics, this study aims to highlight existing challenges and propose potential avenues for future research in DSRC algorithm development

Introduction :

As time passes, the problem of road traffic becomes increasingly challenging. Traffic congestion is a major issue for the general public in crowded areas, particularly in metropolitan areas. Government, academia, and industry have made significant investments in intelligent transportation systems (ITS), which have resulted in the development of safety and traffic management technology in automobiles and road infrastructure. According to official estimates, traffic jams, car accidents, and fatalities reduce Europe's gross domestic product (GDP) by up to 3%. [1] Transport is a crucial sector for the growth of companies and accounts for more than 40% of final energy consumption in the European Union and is a source of CO₂ emissions. [2] A high percentage of congestion directly correlates with increased fuel consumption and pollution.

[3] Figures and worries from the European Union indicate that by 2050, closely related freight and passenger transport operations will rise by 82% and 50%, respectively; [4, 5] According to a recent study by the German regional economic research centre, a driver spends at least 40 hours a year stuck in traffic and congestion [8]. Prior to the COVID-19 pandemic, official reports from the Global Burden of Diseases (GBD) indicated that traffic accidents will rank as

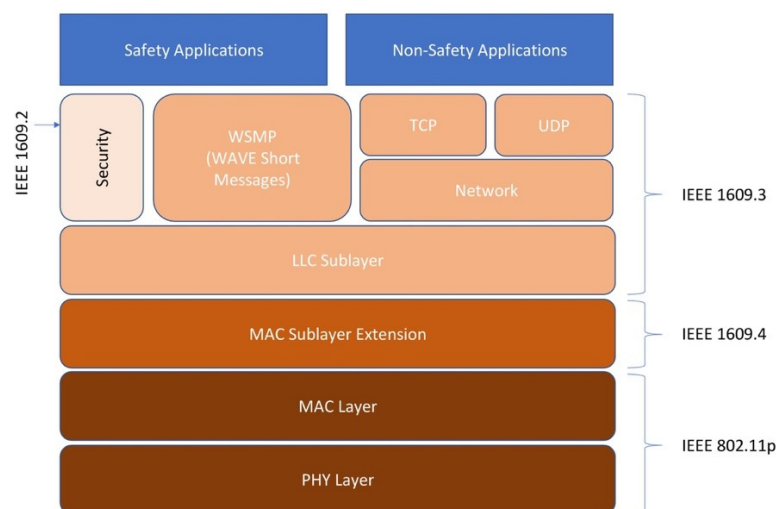
the second most common cause of death and economic loss globally by 2020, with human error accounting for 90% of accidents.[9] The United States Department of Transportation (US DOT) announced intentions in 2011 to assist the deployment of vehicle-to-vehicle (V2V) communication among light-duty automobiles in the United States, often known as "Connected Vehicles" [1-4].[17] In the United States, a study conducted in 2015 stated that traffic congestion was the primary cause of a US\$160 billion yearly loss, including 3.1 billion gallons of wasted gasoline and 6.9 billion hours of lost productivity [11].

The evolution of intelligent transportation systems (ITS) hinges on robust V2X communication frameworks that ensure seamless interaction among various entities within the transportation ecosystem. DSRC, based on the IEEE 802.11p standard, has been instrumental in providing the necessary infrastructure for such interactions, primarily due to its low latency and high reliability. This paper also delves into the core algorithms that constitute the DSRC framework, offering a detailed examination of their functionalities, strengths, and limitations.

1: Overview of DSRC communication, WAVE and IEEE 802.11 p Standards :

In the 1990s, DSRC was a communication technology for ITS applications that were more rudimentary, including electronic toll collection. Today, however, DSRC is used to refer to WAVE, a communication technology created to provide higher-level application services. [16] In general, the 5.9 GHz band (5.850 GHz - 5.925 GHz in the US [17], 5.855 GHz - 5.925 GHz in Europe [18]) has been designated as the operating range for V2X DSRC activities. [19] Additionally, it is almost patent-free, simple to use, and inexpensive to install.[19] Researchers are currently becoming more familiar with DSRC, and the majority are aware that technological problems can be fixed.[16]

The availability of 75 MHz of bandwidth in the vicinity of 5.9 GHz that is set aside for safety purposes is another advantage for enabling DSRC. [16] The majority of manufacturers are starting to employ and integrate V2X-DSRC systems for production cars, including the VAG Group, Volvo, and Daimler Group.[7] The DSRC technology complies with the demands of the active safety applications since it generates a delay of 0.2 microseconds, according to research and findings from prolonged simulations.[7]



Wireless Access in Vehicular Environment (WAVE) is a word used to define the IEEE P1609 protocol suite. WAVE is a rather complicated system that builds on the IEEE 802.11 standards by making several changes to ensure the speedy and reliable transmission of safety information. WAVE is the foundation of DSRC [16]. The highest data rate of 27 Mbps at the 5.9 GHz frequency is what WAVE aims to achieve. Unregistered apps cannot use WAVE services because of the WAVE requirements. Compared to prevalent WiFi standards, this regulation raises the security level for WAVE.[16]

1.1: DSRC/WAVE Standards:

Table 1: IEEE standards and mechanism

IEEE 1609.1	Resource Manager
IEEE 1609.2	Security Services for Applications and Management Messages
IEEE 1609.3	Networking Services
IEEE 1609.4	Multi-Channel Operations

2. Medium Access Control (MAC) Algorithms

The MAC layer in DSRC is crucial for managing access to the shared communication medium, ensuring efficient and collision-free data transmission.

2.1 Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)

DSRC employs CSMA/CA as its primary MAC protocol. Vehicles sense the channel before transmission to detect ongoing communications, thereby minimising collisions. If the channel is idle, the vehicle proceeds with transmission; if busy, it defers and retries after a random backoff period. While CSMA/CA is effective in reducing collisions, its performance can degrade in high-density traffic scenarios due to increased contention and potential delays.

2.2 Enhanced Distributed Channel Access (EDCA)

To prioritise safety-critical messages, DSRC incorporates EDCA, which assigns different access categories with varying contention window sizes and inter-frame spaces. This differentiation ensures that high-priority messages, such as collision warnings, gain quicker access to the channel compared to non-critical data. However, the challenge lies in fine-tuning these parameters to balance the needs of diverse applications without causing starvation of lower-priority messages.

3. Resource Allocation Algorithms

Efficient resource allocation is vital for optimising network performance, especially in dynamic vehicular environments.

3.1 Semi-Persistent Scheduling (SPS)

SPS is designed to reduce control overhead by allowing vehicles to reserve resources for periodic transmissions. Once a vehicle selects a time-frequency resource, it retains this allocation for a predefined duration, minimising the need for frequent re-selection. While SPS enhances efficiency for regular broadcasts, it may face challenges in adapting to rapid topology changes, potentially leading to resource collisions.

3.2 Cluster-Based Resource Allocation

In dense traffic conditions, cluster-based algorithms group vehicles into clusters with a designated leader responsible for intra-cluster communications and resource management. This hierarchical approach reduces contention and improves scalability. However, the dynamic nature of vehicular networks necessitates robust mechanisms for cluster formation and maintenance to handle frequent membership changes.

4. Security Protocols

Ensuring secure communication is paramount to protect against malicious attacks and unauthorized data access.

4.1 Public Key Infrastructure (PKI)

DSRC utilises PKI to authenticate devices and encrypt communications. Each vehicle is equipped with a set of digital certificates issued by a trusted authority, enabling mutual authentication and data integrity verification. The primary challenge with PKI lies in managing the vast number of certificates and ensuring timely revocation in case of security breaches.

4.2 Elliptic Curve Digital Signature Algorithm (ECDSA)

To meet the stringent latency requirements of vehicular communications, DSRC adopts ECDSA for its cryptographic operations. ECDSA offers strong security with shorter key lengths, resulting in faster computations and reduced transmission overhead. Nonetheless, implementing ECDSA requires careful consideration of computational resources, especially in vehicles with limited processing capabilities.

5. Interoperability Mechanisms

With the emergence of alternative V2X technologies, ensuring interoperability is essential for a cohesive ITS ecosystem.

5.1 DSRC and Cellular V2X (C-V2X) Integration

C-V2X, standardised by 3GPP, presents an alternative to DSRC, leveraging cellular networks for V2X communications. To harness the benefits of both technologies, hybrid models have been proposed, where vehicles are equipped with dual radios capable of operating on both DSRC and C-V2X. Algorithms in this context focus on dynamic interface selection based on factors like network congestion, latency requirements, and signal quality. Developing seamless handover mechanisms and unified protocol stacks remains a critical area of research. a key technology for autonomous vehicles, smart cities, and intelligent transportation systems.[12] There are two contenders for the V2X communication enabler, namely Cellular-V2X (C-V2X) on the basis of LTE and 5G cellular networks and Dedicated Short Range Communication (DSRC). Vehicular networks include a variety of communication types, such as vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian (V2P). With the use of various technologies, connected vehicles concentrate on localised V2V, Vehicle-to-Infrastructure (V2I), and Vehicle-to-Device (V2X) systems to support safety, mobility, and environmental applications. [17] In several areas, including communication performance within the effective communication range, collision avoidance, and safety messaging, DSRC has proven to be superior to LTE. Dedicated Short-Range Communication (DSRC) stands out as a prominent V2X technology, facilitating low-latency and reliable communications essential for vehicular safety and efficiency. Wireless vehicle-to-everything (V2X) communication is used by connected autonomous vehicles to communicate information in order to increase road safety and travel convenience, lessen traffic jams, use less fuel, and improve the entire driving

experience. [13, 14] Vehicle-to-everything (V2X) communication refers to this information exchange between vehicles and associated communication endpoints over wireless [15].

Table 2: 4G LTE verses DSRC

Scenarios	LTE – 4G	DSRC
Collision Avoidance	Not better than DSRC	Better than LTE
Traffic Text Message Broadcast	Better coverage	Better than LTE (within effective range)
Multi Media File download	Better than DSRC	Not better than LTE

6. Applications of DSRC:

The use of V2X spans a wide range of areas, including automated driving, intelligent transportation, and intelligent linked vehicles [20]. The requirements for latency, dependability, throughput, user density, and the security of the V2X environment vary depending on the application [21]. Very low latency and a secure networked environment are needed for safety applications and autonomous driving [22, 23]. For instance, because automobiles frequently travel at high speeds, malevolent attackers may also do the same by disseminating misleading information and causing major traffic accidents. By intercepting data packets, malicious attackers may also be able to learn the name of a car owner, the position of the vehicle, the driving trajectory, and other details [24]. User privacy has been violated. The V2X data contains geographic and road-related data that is relevant to national security. So, security is the top priority for V2X [25].

Currently, there are three types of applications that have been created or that will be used soon: safety applications, efficiency applications involving personal safety, such as accident alerts, road danger warnings, and speeding warnings. Apps that help drivers travel more safely and efficiently, such as green wave speed guidance and congestion warnings, are referred to as efficiency apps. The term "information services applications" refers to software programs that give owners access to vehicle-related information to enhance the driving experience, such as eCall, traffic data and route suggestions, and automated parking. The V2X will eventually fulfil the criteria for applications in intelligent traffic systems and advanced automated driving as communication technology advances. For these advanced application scenarios, the 3GPP defines four categories of applications: vehicle platooning, advanced driving, extended sensors, and remote driving [22]. The aforementioned apps are all brand-new applications that emerged as a result of the development of V2X. However, a lot of conventional mobile apps, such as entertainment services, will gradually make their way into the V2X sector.

Low latency is a crucial requirement for safety applications like collision avoidance, and direct V2V communication minimises message delay. An on-board unit (OBU) is more likely to be incorporated and linked to the vehicle's other electronic systems via in-vehicle networking

technologies like FlexRay and the controller area network (CAN), whereas an MS is often disconnected from the CAN. WAVE networks can significantly contribute to toll collection, travel planning, logistics, traffic management, congestion reduction, navigation, emergency services, fleet and asset management, environment monitoring, smart parking, and a host of other location-based services in addition to enhancing safety. [26]

7. Summary on Simulated V2X application and real-world experiments:

The maximum range, packet delivery rate (PDR), and packet inter-reception time (PIR) are three variables that the author used to compare V2V and V2I in real-world circumstances with what is indicated in the NS-3 simulator. [28] In both cases, V2I and V2V, the results reveal that only the modulation associated with the 6 Mbps PHY rate provides a suitable range of 700 m. [28] While the increase in speed in simulations leads to a decline in PDR, the same was not found in the actual measurements because the results from simulation and practical trials are not equivalent. On the other hand, constant movement has an impact on communication in both situations. [28]

The results of IEEE 802.11p field testing were reported in this study in order to evaluate short- and medium-range application-level performance for safety-related applications. The findings show that under difficult network and environmental circumstances, appropriate transmission power is essential for ensuring the timely and effective delivery of safety-critical signals. At the network, transport, and application levels, [29] looked at five distinct performance indicators: TCP Goodput, UDP Goodput, Round-Trip Time (RTT), Jitter, and Datagrams Lost or Packet Delivery Ratio (PDR). [29]

The capability of the system and architecture developed by Cohda Wireless, based on Mk5-OBUs, may communicate in the dual band at frequencies ranging from 780 MHz to 5.9 GHz, and it may give applications and field contributions. Given that the measurements were conducted in the early stages without the use of a full OBU (On Board Unit)-RSU (Road Side Unit) system, we can conclude that they are notable in that the coverage area is significantly larger than what is required by the 802.11p standard. According to the scenarios, the two OBU-Mk5 modules could be connected in a straight line no more than 900-1000 meters apart. In [7], the procedure was carried out in a busy place 200 m from the transmitter, in accordance with the situations indicated. Although the short-distance measurements in a controlled environment in the early stage highlight the dependability of the 802.11p standard, there were distortions or interruptions in the message transmission process when the dynamics of the objects and the vehicle's mobility were disrupted once again. These experiments [7] demonstrate the standard's adaptability to environmental dynamics as well as its ability to fit into circumstances involving a range of network pathways and nodes. [7]

8. Challenges and Future Directions

Despite great advances, some obstacles remain in the field of DSRC algorithms.

- **Scalability:** As vehicular density increases, ensuring that MAC and resource allocation algorithms can scale without performance degradation is imperative.
- **Security:** Developing lightweight yet robust security protocols that can operate within the processing constraints of vehicular hardware is essential.

- **Interference Management:** With the proliferation of wireless devices, algorithms must effectively mitigate interference to maintain communication reliability.
- **Standardisation:** Harmonising standards across regions and technologies is crucial for global interoperability.

Conclusion:

A DSRC-enabled ITS system must be protected against misuse and attacks with diligence. Due to higher mobility, more Doppler spread, and multipath delay spread, WAVE devices must contend with rapid frequency selective fading. Fundamentally, WAVE networks need to be very strong since failure might result in the loss of people and property. A choice based on delayed information might be very detrimental since some messages delivered over a WAVE network have strict latency requirements.

The major challenge is to develop reliable, scalable, low-latency, high-throughput technology for safety applications that would drastically minimise collisions, save lives, and prevent property loss. To overcome this challenge, further research is still going on in different areas. The future research should include an analysis of the requirements of the application, ITS-related studies, some protocol stack optimisation, a good simulation system with larger data, general people awareness of ITS, etc.

Future research should focus on adaptive algorithms that can respond to the dynamic nature of vehicular networks, incorporating machine learning techniques to predict and react to changing conditions proactively.

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