Chapter 2
Vehicular Ad hoc Networks

The Intelligent Transportation System (ITS) is a cutting-edge technology that provides information and communication capabilities to transportation networks. By doing this, ITS ensures efficient and safe transportation services [35]. Vehicular Ad-hoc Network (VANET) is the key technology that can realize ITS goals by establishing communications between vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V)[64]. Vehicular Ad-hoc Networks (VANETs) are self-organizing networks that enable information exchange among moving vehicles without the need of any central coordination. VANETs have the potential to enhance traffic safety, travel efficiency, and driver convenience. VANETs have characteristics that distinguish them from standard wireless networks and make them useful for dynamic traffic scenarios. Some of these properties include, but are not limited to, maintaining connectivity despite high mobility, requiring no central coordination, supporting single-hop and multi-hop communications, etc. On the other hand, obstructions, a shorter communication range, and limited bandwidth resources are some of the limitations VANETs have.

2.1 VANET Architecture

Figure 2.1 presents an example of VANET architecture. The Road Side Unit (RSU) and the On Board Unit (OBU) are the two main components of a VANET[2]. Each vehicle is equipped with numerous sensor and processing devices capable of collecting and processing data, as well as an OBU enabling short-range wireless communication with other OBUs or RSUs. These devices are essential components of VANETs and perform the tasks of a receiver, a transmitter, and a relay node, depending on the circumstances. Each vehicle will also have a user interface

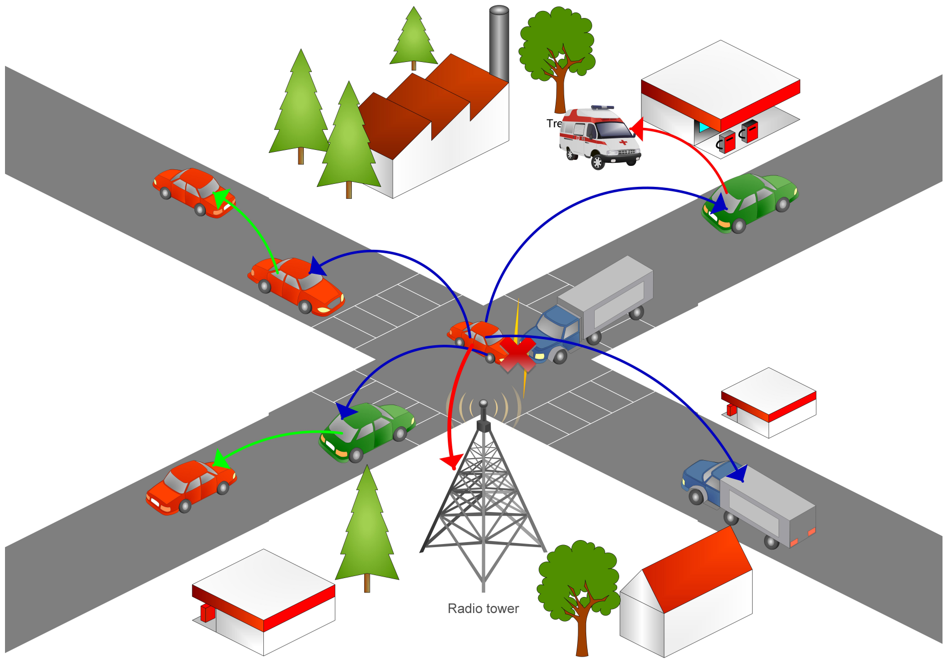

Figure 2.1: VANET Architecture

and an application unit (AU) so that it can offer different ITS applications [7].

On Board units: OBUs are intelligent wireless devices installed inside the vehicles. OBUs are able to connect with other OBUs and with RSUs through network devices for dedicated short-range communication based on IEEE 802.11p radio technology. Other than wireless connectivity, OBUs also have sufficient processing power and memory resources.

Road Side Units:RSUs are similar devices to OBUs but are installed along the road infrastructure. Different RSUs can communicate with each other. The main tasks of RSUs are to: *(i)* convey information to moving vehicles; *(ii)* provide internet connectivity to OBUs; and *(iii)* extend the range of OBUs by conveying messages from one OBU to another.

Application unit: It is a dedicated or portable device directly connected with OBUs. AU provide user interface to access different ITS applications.

2.2 V2V and V2I communication

Vehicles exchange data to increase the safety and efficiency of transportation. This data exchange is facilitated by a vehicular ad hoc network. There are mainly two types of data communication models in VANET [2].

Vehicle-to-Vehicle (V2V) communication: In V2V, vehicles connect with other vehicles using their OBUs to build a fully distributed mobile ad hoc network that does not require any central coordination. The key challenges for this type of communication are:*(i)* a shorter communication range;*(ii)* intermittent connectivity; and *(iii)* bandwidth limitations. Mostly safety-related communication occurs through this mode [1].

Vehicle-to-Infrastructure (V2I) communication: In this mode of communication, dedicated RSUs or other wireless connectivities (such as cellular networks, Wi-Fi) are used as infrastructure along with OBUs. V2I is used mainly to:*(i)*increase the range of V2V communication; *(ii)* pass information in vehicular networks; *(iii)* provide internet connectivity in V2V; and *(iv)*integrate other wireless services with V2V. Figure 2.2 shows V2V and V2I communication mod-

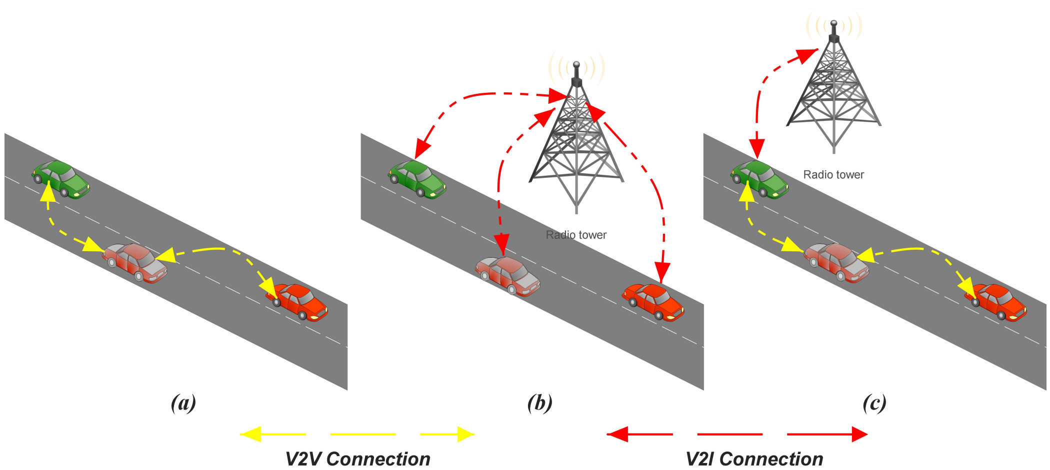

Figure 2.2: Types of Inter-vehicle Communications (IVC)

els. Vehicular communication modes can be fully V2V, V2I, or hybrid, in which V2V and V2I modes are integrated. Sometimes V2I mode also includes other communication technologies and is referred to as "vehicle-to-everything" (V2X) communication.

2.3 VANET Characteristics

VANETs are a subset of mobile ad hoc networks (MANETs) due to a number of distinguishing characteristics [2],[40].The characteristics are as follows:

- Restricted mobility: Mobility is restricted because of the topology and layout of the road. Plus, vehicles need to obey traffic patterns and road signs.

- Unlimited power: Unlike MANETs, vehicles can continuously provide power to OBUs through their batteries.

- High processing power: Vehicles can be equipped with high-performance processors, memories, and storage to effectively process received information.

- Dynamic network density: Vehicular network density can vary from time to time and location to location. High network density can result from traffic jams or urban areas, whereas highways or rural areas can result in very low network density.

- Dynamic network topology: Due to the high mobility of vehicles in VANETs, the link-lifetime is extremely short. It is specifically dependent on the actual radio range and vehicle movement direction.

2.4 VANET standards

2.4.1 DSRC Overview

The new wireless technique for vehicular communication is called Dedicated Short Range Communication (DSRC)[22]. The United States Federal Communications Commission (FCC) assigned 75 MHz of licensed spectrum in the 5.850–5.925 GHz frequency band for it[59],[14]. As shown in Figure 2.3, the DSRC frequency band

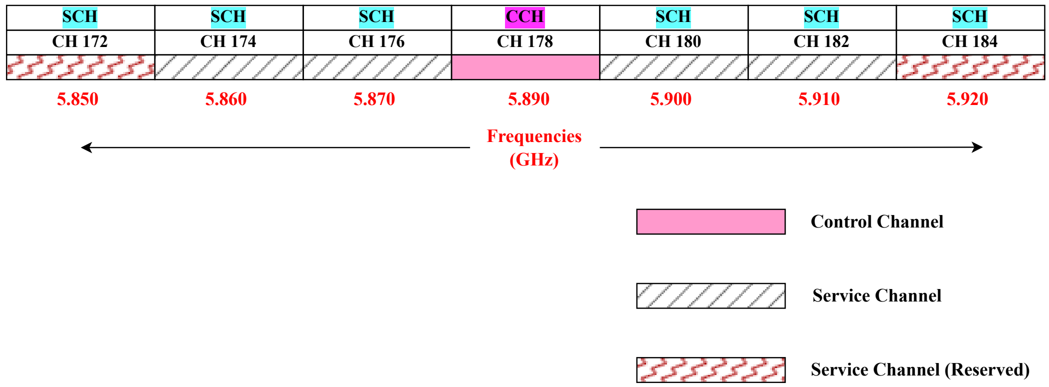

Figure 2.3: DSRC Spectrum

is divided into one control channel (CCH) and six service channels (SCHs)[29]. One Control Channel (CCH) is exclusively reserved for safety application-related message exchange. Six remaining channels, known as Service Channels (SCH), are utilized for both safety and non-safety purposes, including infotainment, entertainment, etc. [11]. DSRC employs IEEE 802.11p at the physical (PHY) and medium access control (MAC) layers, which is a modified version of the IEEE 802.11 (WiFi) standard.

Physical Layer: The physical layer of IEEE 802.11p is similar to IEEE 802.11a, with VANET-specific modifications. The IEEE 802.11p PHY reduces the signal band from 20 MHz to 10 MHz. These changes increase communication reliability but at the expense of slower data throughput (between 3 and 27 Mbps). The physical layer protocol consists of two sublayers: the physical medium-dependent (PMD) sublayer and the physical layer convergence procedure (PLCP) sublayer. PMD directly interfaces with the wireless medium. It employs the well-known orthogonal frequency division multiplexing (OFDM) method similar to 802.11a standards. PLCP maps the MAC frame to the fundamental PHY layer data unit. PLCP adds phy overhead to the MAC frame to create the Phy Protocol Data Unit (PPDU). At the transmitter side, PLCP processes the MAC frame to convert it into OFDM symbols. The MAC layer conveys information regarding frame length, data rate, and transmit power to PLCP. The PMD transmitter performs

OFDM modulation and transmits PPDU over the air. At the receiver side, PMD performs demodulation and passes the received frame and RSSI value to PLCP.

MAC Layer: It is a modification to the IEEE 802.11 standard family designed to handle the extremely dynamic VANET environment. Consequently, the MAC layer is modified to ensure immediate communication between vehicles without requiring authentication or association. As a channel access scheme, it uses CSMA/CA. In which clear channel assessment (CCA) is performed to indetify idle channel. A back-off process is utilized to avoid collisions. If a vehicle has to send a frame, it first scans the channel for Distributed Inter-Frame Space(DIFS). If the medium is idle, the vehicle initiates frame transmission. If the medium is occupied, the vehicle will perform random back-off in order to wait before transmission. The countdown begins when the medium goes idle.

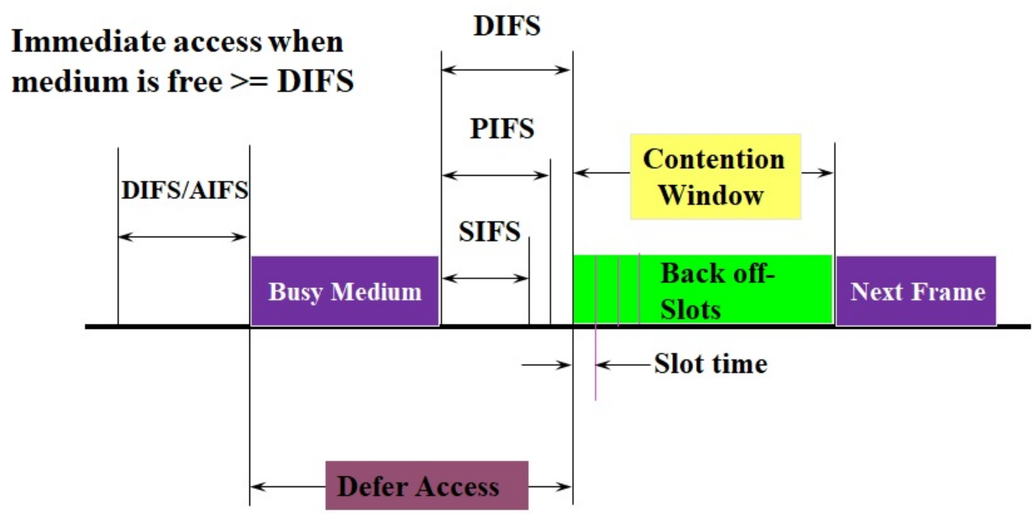

Figure 2.4: Channel access procedure in IEEE 802.11

Figure 2.4 shows the DCF-based channel access procedure. To confirm packet delivery in unicast mode, the sender employs an acknowledgement-based scheme. To avoid the hidden node problem, it uses RTS-CTS-based communication. However, in broadcast communication, acknowledgment is not used [39].

The MAC layer provides a quality-of-service mechanism known as Enhanced Distributed Channel Access (EDCA). The four Quality of Service (QoS) classes are enabled by EDCA by providing data priority. Hence, each node maintains four queues. Different back-off settings and Arbitrary Inter Frame Spacing (AIFS) are used in these queues; the shorter the AIFS, the higher the priority.

2.4.2 WAVE Protocol Stack

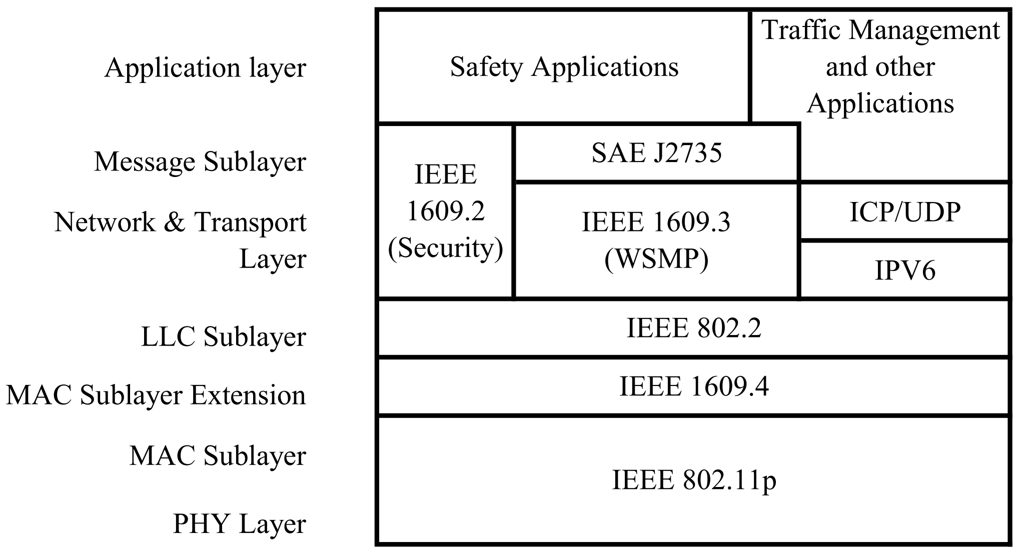

Figure 2.5: WAVE Protocol Stack

Different standardization bodies related to the Intelligent Transportation System (ITS) have made efforts to develop common communication standards exclusively designed for vehicle communication to achieve the main goal of efficient and safe road traffic. In this context, the Institute of Electrical and Electronics Engineers (IEEE) has proposed the complete WAVE protocol stack, which is the most popular among research and industry. In particular, WAVE uses the IEEE 1609 and 802.11p standards to specify the operational guidelines for vehicular communications[46].

The physical and MAC layers of WAVE are governed by IEEE 802.11p standards, whilst the network, security, and application layers are governed by IEEE 1609 standards. IEEE 802.11p, as previously stated, is a customized version of the 802.11 family standards for vehicular communication.

The following four elements make up the IEEE 1609 standard for Wireless Access in Vehicular Environments (WAVE): IEEE 1609.1 provide resource management for different ITS applications, whereas IEEE 1609.2 is dealing the security issues like secure message formats and processing. Services at the network and transport layers are provided by IEEE 1609.3 and IEEE 1609.4 deals with multi-channel operation. Figure 2.5 presents WAVE protocol architecture.

2.5 VANET Applications

As was already noted, VANET is a crucial component of the Intelligent Transportation System (ITS) and can guarantee road users'comfort and safety. In this context, vehicular communications are used to support a variety of applications [17]. ITS applications can be divided into three categories: (i) road safety applications, (ii) traffic management applications, and (iii) infotainment applications [23], [11].

2.5.1 Road Safety Applications

They are regarded as the most important and valuable category since they are designed to increase road user safety and decrease fatalities. Their major goal is to let drivers exchange emergency information and coordinate among themselves to enhance their travel experience and avert accidents or critical situations. Overtaking warning, collision warning, intersection collision warning, post crash alerts are few examples of safety applicaitons [54]. While disseminating safety alerts, these applications require a high reliability and low latency. Early reception of alerts will allow drivers to perceive the warning signal and take necessary action such as braking, changing lanes, and so on. According to their transmission patterns, the message types are divided into two main categories: periodic beacon messages and event-driven safety messages. *Beacon messages* are short messages that are periodically broadcast by moving vehicles to inform their neighbors about their location, speed, direction, type etc. On the basis of this information exchange, each receiver became aware of the nearby vehicles. Additionally, this information could enable a number of ITS applications (such as traffic jam, emergency alerts, sudden braking events, lane change warning, etc). *Event-driven alerts* are only activated when a emergency event is identified. The purpose of alert broadcast is to inform all concerned vehicles within an area of interest, of a possible risk on the road or an emergency situation. This message conveys the event classification and its locaitons. To cover larger geographical area, it is disseminated through V2V and V2I communication models [54].

2.5.2 Traffic management applications:

Traffic management apps are focused on enhancing traffic flow. For example: co-operative cruise control, cooperative navigation, traffic jam detection, an alternate route to avoid a jam, etc [17].

2.5.3 Infotainment applications:

The goal of infotainment applications is to provide convenience to drivers and passengers[45]. Vehicle users can use a wide range of infotainment apps at any time and in any place. This means that Internet access is needed in moving vehicles. Infotainment applications include media download, streaming, VoIP, social networking, gaming, etc. Through service channels, passengers will have access to infotainment applications. Several of these applications rely on delay-sensitive streaming, demanding real-time communication. As a result, infotainment apps need to be very reliable and have a low end-to-end delay.