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Types of Communication in Vehicular Ad-Hoc Networks: Various Techniques and Current Challenges in this Field

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Abstract

With the development of technology and the growing number of vehicles, ad-hoc vehicular networks have been introduced to reduce road accidents and increase the safety level and comfort of passengers. In these networks, vehicles can communicate with each other, with road equipment and other network components. Communications in VANET were established for fast and accurate transmission of integrated information from vehicles and infrastructure to other vehicles and infrastructures via wireless networks, which play an important role in network performance, quality of service, safety, and traffic congestion rate. In this article, we have categorized the types of communication in this type of network. Also, we have reviewed and categorized the work done in this area based on various purposes in tabular form. Finally, we presented certain aspects and challenges of research in this area that need to be solved.

Keywords: Vehicular Ad-Hoc Network (VANET), Intelligent Transportation System (ITS), Communications

1.Introduction

According to the World Health Organization (WHO), road accident and injury rates in all countries indicate that road accidents are one of the leading causes of death after the year 2000. To this end, a suitable traffic system was presented and implemented to address this problem. A vehicular ad-hoc network (VANET) is an advanced network and subset of mobile ad-hoc networks (MANET) primarily providing intelligent transportation system (ITS) services to drivers with the aim of providing a fast and timely data exchange, efficiency, and security [1, 2]. VANET networks have a highly dynamic, random and unreliable environment. The vehicles in this network are equipped with various sensors, computing power, and wireless communication. The network uses various standards such as DSRC and WAVE to transmit data quickly and accurately. Since the use of the MANET network routing protocols in VANET networks is difficult to implement due to the high mobility of vehicles in the network and frequent changes in the network topology, new routing protocols for the VANET network have been developed. Frequent changes in VANET networks have led to challenges in data communication, application design and production in VANET networks [1, 2].

The main purpose of deploying a VANET network is to reduce the frequency of incidents and road accidents. This greatly affects passenger comfort, transportation system efficiency and safety. To this end, communications have been established in VANET for the fast and accurate delivery of integrated information from vehicles and infrastructure to other vehicles and infrastructure via wireless networks, which play an important role in network performance, quality of service, safety and traffic congestion rate [2]. In this article, the types of

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communication in the VANET network are divided into four main categories. In VANET networks, on-board units in vehicles can communicate with each other via vehicle-to-vehicle (V2V) communication. These units can also communicate with the road infrastructure via infrastructure-to-vehicle (I2V) or vehicle-to-infrastructure (V2I) communications. Another type of communication in the VANET network is the combination of V2V and V2I communication, called V2X communication, which plays an important role in the future architecture and structure of ITS. V2X is a wireless technology that can reduce environmental impact to improve road traffic management and increase driver and road safety. The term V2X includes V2V, V2I, V2R communication and finally vehicle communication with the universe, V2U (universe means everything like public safety, satellite, pedestrian, GPS, cloud services, mesh, etc.) [2-4].

The purpose of this article is to present some research challenges and aspects to explain the above communication and the work done in this field. The rest of the article is structured as follows: In the next section, the types of communication in vehicular ad-hoc networks are briefly described. Then the work and research carried out using different types of communication expressed in the VANET network are reviewed briefly. Then we classified them in terms of driver and road safety, passenger entertainment and driver convenience, development of communication structure, achievement of system QoS, improvement of traffic congestion, reduction of delay in data transmission, increase of Packet Delivery Rate (PDR), improving computational and communication costs in one table. In the last section, some research aspects and challenges in this field were presented and finally, the article was concluded in this section.

2.The Types of Communication in Vehicular Ad-Hoc Networks

In this section, the types of communication available in vehicular ad-hoc networks are presented and then the work carried out in different areas related to each type of communication is exhibited in a table with more details. Communication in the VANET network means integrated information containing information about driving environment, vehicles and driver status of vehicles and infrastructures to other vehicles and infrastructures in a timely manner and with high precision through wireless networks. Due to the high speed of vehicles in the VANET network, communication in this network is inherently unstable and is usually used to control road traffic, increase the safety level of passengers and drivers, their convenience and network efficiency [5]. In this paper, communications in VANET are divided into four major groups (as shown in Fig. 1):

- Vehicle to Vehicle Communication (V2V)
- Vehicle to Infrastructure Communication (V2I)
- Infrastructure to Vehicle Communications (I2V)
- Vehicle to Everything (vehicle/ infrastructure/ roadside equipment/ universe, such as: satellites, grid, pedestrians, cloud services, etc.) (V2X)

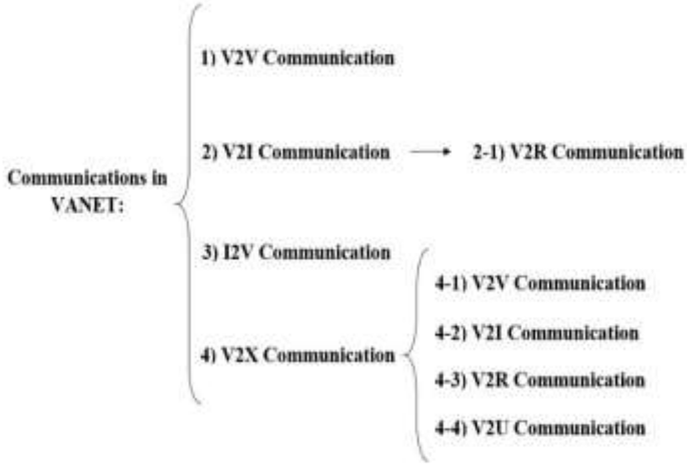

Fig. 1. The types of Communications in VANET

In VANET networks, on-board units (OBUs) embedded in vehicles can communicate with each other via vehicle-to-vehicle communication (V2V). This type of communication on the VANET network uses multi-hop connectivity (including broadcasting or multicasting) to exchange data to ensure driver and traffic safety. In addition, these OBUs can communicate with fixed infrastructures known as roadside units via infrastructure-to-vehicle (I2V) or vehicle-to-infrastructure (V2I) communications [3].

This type of communication uses one-hop connectivity (roadside units broadcast the desired messages to the vehicles within their communication range, or the vehicle communicates to the roadside units the essential information provided, such as the occurrence of an accident or incident on the road). It also uses a higher bandwidth connection between vehicles and roadside units. Roadside units with vehicle speed monitoring and management, when they spot vehicles traveling at unacceptable speeds, send an alert to target vehicles [2, 3].

Another type of communication in the VANET network, as shown in Fig. 2, is a combination of V2V and V2I communication, called V2X communication, and plays an important role in the architecture and structure of the intelligent transportation system [4]. V2X is a kind of wireless technology that can reduce environmental impact to improve road traffic management and increase driver and road safety. The term V2X includes V2V, V2I, V2R and V2U communications (here the universe means satellite, cloud services, traffic lights, GPS, Grid, pedestrian, public safety, etc.) [2-4].

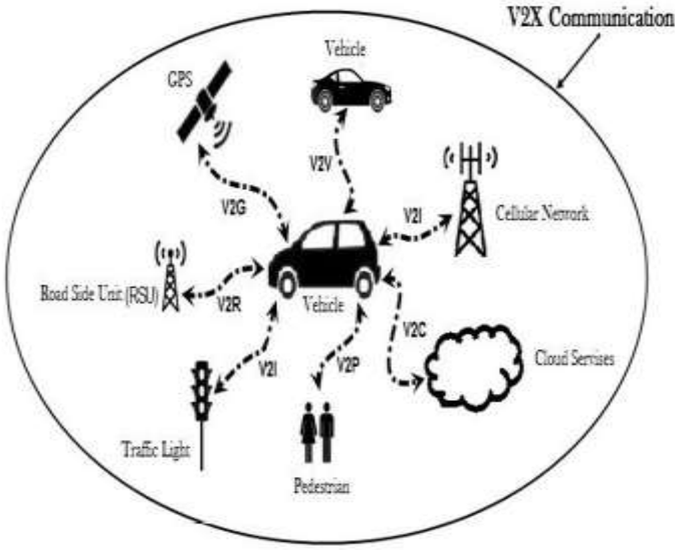

Fig. 2. Communications in VANET

The following briefly describes each of the above communication types and summarizes the work carried out with different objectives to improve system performance, as well as user comfort, driver safety, and the development of the communication structure in each of these communications.

2.1.Vehicle to Vehicle Communication (V2V)

As shown in Fig. 3, one form of communication in VANET networks is vehicle-to-vehicle communication. Vehicle-to-vehicle (V2V) communication plays an important role in vehicular ad-hoc networks and intelligent transportation systems in general, where vehicles communicate with each other using wireless devices [6]. The purpose of this type of communication is to improve driver and road safety, raise drivers' awareness of current road traffic, provide valuable and useful information about road conditions and weather status, and carry out control operations, large-scale measurements and make decisions. Using this communication in applications will save time and preserve the health and life of people on the street. This type of communication saves time and keeps people healthy by sending alerts to inform drivers about events on the road or predicting traffic jams [6, 7].

In V2V communication, the issue of security and connection maintenance is very important and issues such as latency are less considered since the security and connectivity parameters depend on the neighboring participating vehicles. Applications aiming to maintain traffic and driver safety (e.g. accident or disruption warning, road integration, emergency braking, etc.) can be deployed using this type of communication. In this type of application, vehicles can prevent accidents by wirelessly communicating with each other by sending periodic messages [6, 7].

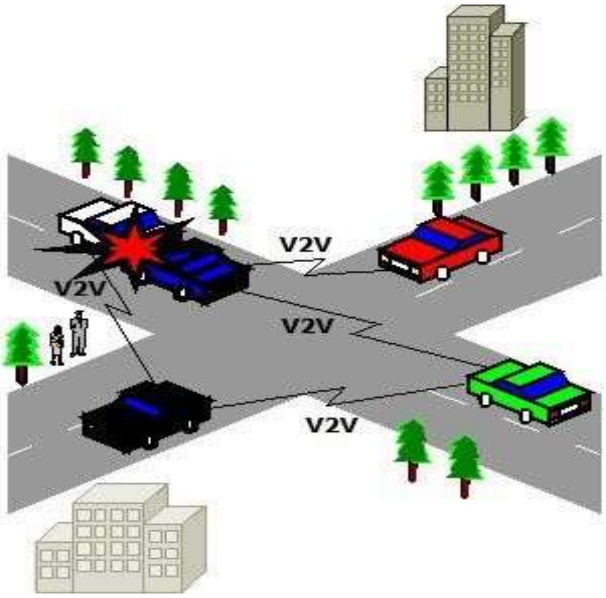

Fig. 3. Vehicle to Vehicle Communication (V2V)

V2V communication uses IEEE 802.11p to establish vehicle communication with road safety applications or applications for the purpose of entertainment or transmission of large amounts of data. This standard, called dedicated short-range communications, ranges from 5.850 GHz to 5.925 GHz (75 MHz radio frequency) for vehicular communications. DSRC is used to detect current errors in vehicle trajectory for V2V communications. Even if the driver cannot find the errors in his driving route, this standard can be used that the communication range of DSRC for V2V communication is 300ms at most. V2V technology uses a variety of radars and cameras to measure and provide information about the traffic situation in the area [7, 8].

Accident warning messages were broadcast through multi-hop V2V communication, which is suitable and convenient for short communication distances. The vehicles communicate with each other using different communication protocols and after transmitting an emergency message from one vehicle to another, the recipient of the message performs the necessary actions according to the received message [8]. In fact, in this type of communication, you use multi-hop communication (broadcasting or multicasting) to transmit data and improve driver and road safety, raise drivers' awareness of the current road traffic, and provide valuable and useful information about the road situation and weather conditions [7-9].

To prevent incidents and collisions in V2V communication, broadcasting and multicasting based on location are used. Multi-hop communication transmits the message without the presence of a roadside unit. However, in low-density vehicular networks, V2V communication is less useful because the distance between vehicles is large. Also, for sending in this type of communication, there are two ways of sending messages between vehicles: simple broadcasting and smart broadcasting. Due to the fact that in simple broadcasting, the number of generated messages is large and data is not well utilized, an smart broadcasting method has been proposed to solve this problem [8].
In V2V communication, communication links are divided into three groups [10]:

- Line of sight (LOS): A link that has an optical path between transmitter and receiver without the existing obstacle.
- Non-Line of Sight (NLOSv) due to vehicles: The link whose LOS is blocked by other nearby vehicles.
- Non-Line-of-Sight (NLOSb) Due to Obstacles or Buildings: Connection blocking the LOS through obstacles such as tree leaves, or buildings.

The line of sight (LOS) between transmitter and receiver may or may not be due to the dynamic nature of V2V channels as vehicles travel at high speeds in the network and the antenna height is short. In addition, this type of communication uses two methods of direct relay (multi-hop transmission between vehicles) and transmission relay (storage and transmission) of spread information [10, 11].
Commonly, the data sent to vehicles includes the following [12]:

- Current velocity
- Present GPS position
- Trajectory and acceleration of the vehicle.
- Vehicle control information (brake status, gearbox status, steering lock angle)
- Vehicle route history and predicted path
- Deviation rate from the trajectory.

The main features of vehicles with V2V technology are as follows [12]:

- Cameras
- Radar/ultrasonic/laser distance sensors
- Radio transceivers
- Radio transmitters
- GPS antennas and DSRC antennas
- GPS receivers
- Processor and its memories

Different applications in the field of safety warning have been presented with the help of V2V communication, such as: sending an accident warning, blind spot warning or lane change warning, Emergency braking action warning, etc [12]. Numerous researches in different fields using this type of communication (V2V) have been presented, which are briefly reviewed below.

In order to provide the performance of sending information as a function in V2V communication, a mathematical formula for intrusion of equipped vehicles was introduced in 2010, estimated for all LOS and suitable to study the information path in busy routes and areas with high penetration [11]. Another 2010 article presented a multi-faceted agent trust modeling method for effective V2V communication by intelligent agents. This method resulted in more effective information and prevented false information being sent by limiting the number of reports received from vehicle agents [13].

Another 2010 article provided an analytical framework for exploring misbehavior nodes in V2V communications. This work was presented with the aim of reducing the weaknesses of admitted vehicles through delays in the dismissal performance of misconduct nodes [14]. In 2010, another paper proposed a decentralized large-scale authentication protocol to keep VANETs secure. This method helps RSUs to maintain and manage vehicles within their communication range [15]. In 2011, a paper on modeling vehicles as three-dimensional physical barriers was presented. These barriers are effective in V2V communication and have a significant impact on LOS hindrance in both sparse and dense vehicular networks and should be considered in V2V channel modeling [16].

In 2013, a geographical model for diffuse components based on the scattering of objects distributed along the RSU was proposed for the V2V channel with the aim of dispersing the arriving angle and the Doppler spectrum [17]. In 2014, a release model for V2V communication called GEMV2 based on geography was designed. In this method, vehicles, foliage and buildings were used to distinguish three types of lines of light (LOS), non-LOS due to static objects and non-LOS due to the presence of vehicles [10]. In 2014, a relay scheme was introduced with the help of tall vehicles used for V2V communication. In this scheme, tall vehicles were used as next-hop relays and it was called TVR model, resulting in an increase in packet delivery rate and received signal strength [18].

In 2015, a new V2V channel access model called EDF-GSMA was introduced to ensure channel service quality and avoid collisions [19]. In 2016, an analysis of V2V connectivity and data exchange rates in this type of communication was carried out with the aim of establishing fast communication and low communication delay. Mathematical models were used for this [7]. In 2016, another mathematical model for moving vehicles in one direction on the highway was introduced, which was proposed for V2V communication on one side of the multi-lane highway. This mathematical model was proposed to calculate the data packet delivery rate [20]. In 2017, an analysis of the effects of multi-link shadowing on V2V communication by vehicles was presented and modeled using large-scale fading [21].

A secure connection has been proposed using two ID-based signature schemes called IBS and IBOOS with the aim of authenticating interconnected vehicles and network infrastructure in 2017 reducing computational and communication overhead [22]. Another 2017 article introduced a routing protocol called MoZo that aims to improve message delivery rates [23]. Also, another routing protocol called CBL was developed in 2017 using V2V communication. In this method, clustering was used to facilitate routing operations and optimize flooding of messages [24]. With the aim of periodic and non-periodic delivery of messages via V2V communication in 2017, a geolocation-based access analysis was performed. This was used to express the probability of successful message delivery, average binary rate and energy efficiency [25] .

Another work in 2017 presented a decision module using the collision prediction model and V2V communication. With this method, in the event of an accident, a new route is suggested to the driver by re-routing in order to reduce the waiting time and travel time [5]. In 2018, software for accident detection and sending emergency messages to medical service centers was provided by V2V communication and neighboring vehicles. This was done with the aim of saving the lives of the passengers in the event of an accident and providing them with medical care [26]. In 2018, another algorithm called speed-based vertical handover was introduced to reduce significant delays in error message transmission. The proposed method has been studied in terms of output and latency, where the output depends on the bandwidth and speed of the vehicle and the overhead of the control scheme protocol during cell traversal time [8].

Another algorithm called DIAC was developed for routing software in 2018 to assist the driver. This was done in order to have a stable network connection between vehicles and access networks for sending important information, which led to a reduction in the number of communication link failures between network components [27]. In 2018, a review article was presented on the types of communication channels in vehicle software and the use of MIMO to improve the efficiency, high data transmission rate and reliability of the communication system of software in intelligent transport systems [28]. In 2018, another scheduling algorithm based on transmission priority and dependent on network coverage and bandwidth was introduced, which prevented multi-access interference and high-speed Internet access [29]. Another 2018 article presented a vehicle movement model for a specific city called Bhubaneswar. In this work, the performance analysis of DSR and OLSR routing protocols in terms of PDR and average link output parameters was evaluated [30].

In order to increase the transmission rate of important information with the least delay, a secure information dissemination plan for V2V communication based on multi-agents was introduced in 2019 [31]. A control system using GSM towers and 5G technology in 2019 should increase data traffic efficiency and road safety, as well as faster response time [32]. In 2020, a clustering algorithm with a channel allocation mechanism was proposed to neutralize intra-cluster interference. Based on the results of this project, an uplink transmission optimization framework has also been proposed, aiming to increase spectral efficiency and e2e output of multiple concurrent V2V communications [33]. A system based on V2V and V2I communication was introduced to automatically manage traffic and help emergency vehicles find a better route with less traffic in 2020 [34].

2.2. Vehicle to Infrastructure Communication (V2I)

Another type of communication in vehicular ad hoc networks is vehicle-to-infrastructure communication, also shown in Fig.4. This type of communication provides long-range communication over cellular wireless networks and typically uses roadside units and IEEE 802.11p standard communication protocols to create and support V2I protocols. V2I communication provides a high-bandwidth communication link between vehicles and network infrastructures, and is widely used to manage relayed messages to control road traffic, reduce traffic disruptions and accidents, and ultimately improve road safety levels [8, 9].

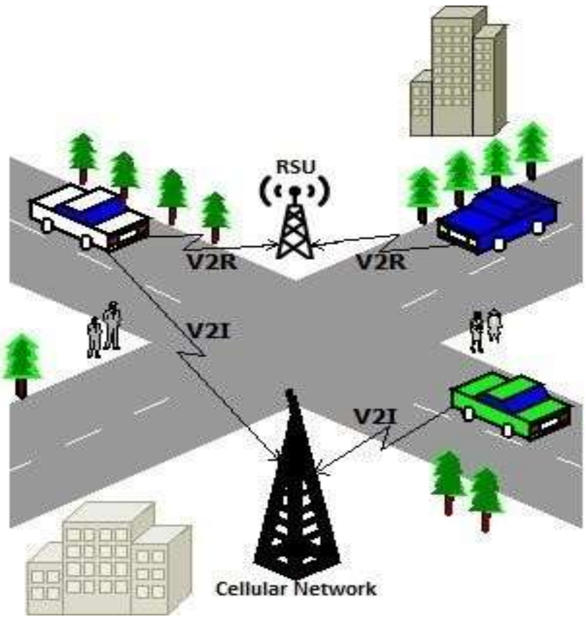

Fig. 4. Vehicle to Infrastructure Communication (V2I) and Vehicle to Roadside unit Communication (V2R)

Infrastructure components within V2I communication may include [9]:

- Cellular network stations
- Traffic light
- Line signs
- Road signs
- Roadside units and...

Messages exchanged between the Roadside Unit (RSU) and the vehicle may contain items such as vehicle position, vehicle route history information, road condition and safety information, variable information about the current route, and so on. Applications supported by V2I communication often include prevention of consequential accidents, weather warnings, road safety and congestion warning, speed limit information and warning of driver overspeeding, road deviation warning, warning of places on the road that are in the under construction or under repair, pedestrian lane warning and red light violation, entertainment services such as video presentation, internet search, sending email and VoIP etc [9].

Roadside Units are deployed to maintain a high volume of data traffic at a distance of one kilometer from each other in traffic jams. The communication between vehicles and the roadside units is performed by the V2R protocol. It can be said that V2R communication is a subset of V2I communication in VANET and in some research these two communication are considered to be the same. V2R communication is used to warn of accidents while vehicles are moving and prevent further accidents and increase traffic safety [8].

With this type of communication, an accident warning message is sent to the first RSU in the current path, and then the RSU broadcasts the message to the vehicles in its communication range. In fact, in V2R communications, when a hazard or defect occurs to the vehicle, the vehicle generates an emergency alert message and holds the message itself ready for retransmission. It then broadcasts the message to its neighboring vehicles as well as to the RSU in its vicinity to receive its message with the same ID from the roadside unit and its rear vehicle.

When the roadside unit receives the message, it replaces its ID with the primary vehicle's ID and broadcasts it to vehicles within range. Since the message is sent from the vehicle to the roadside unit and then from the roadside unit to the target vehicles, the delay parameter is important in this type of communication [8, 9, 27].

In V2R communication, this is done by single-hop broadcasting when the roadside unit sends a message, such as a speed limit warning message, to the vehicle within its communication range. An example of the V2R communication is when the speed limit message is sent, where the roadside unit can determine and check acceptable regulations depending on the internal schedule and traffic conditions. The roadside unit can broadcast the message containing the rules periodically and can compare any geographic restrictions or route restrictions with vehicle knowledge to understand whether or not a speed limit warning has been applied to any of the vehicles in that area. When a vehicle violates the rules sent by the roadside unit (the rules are set according to the traffic situation and road conditions), a visual or audible warning is sent to that vehicle to reduce its speed [35].

Various researches in different fields using these communication modes (V2I and V2R) have been presented, which are briefly considered below.
In 2008, an analysis of the capacity, coverage and scalability parameters of broadcast systems, WAVE, DSRC and cellular communication for establishing V2I connections was presented [36]. In 2012, an intelligent traffic management system called fuzzy-based control algorithm for V2I communication was introduced. This was done with the aim of adjusting the speed limit and safety distance of vehicles to avoid accidents and improve road traffic [37]. An analysis was carried out on the topic of integrated data delivery in V2V and V2I communication and an algorithm based on measurement and coding techniques was presented in 2012 [38]. In 2013, two Markov two-chain solutions for distributed channel access groups were proposed to study the reliability performance in broadcasting important information as well as solving the hidden terminals problem in V2I and V2V communication [39].

Another work proposed a bit-loading algorithm for MIMO V2I communication aimed at studying the effect of spatial correlation and increasing the number of antennas in 2013 [40]. In 2015, a model for detecting dangerous slippery roads was introduced using a fusion of distributed data and V2I and V2V communication. This method has been tested both in simulation and in real time with the aim of avoiding accidents and sending unreliable data [41]. In 2016, a multi-hop connection for V2I communication was introduced, providing a multi-hop path from the source to an RSU using vehicles as intermediate nodes. This stochastic model was proposed with the aim of investigating the availability of the middle node relay and providing the average e2e delay [42].

In 2017, a performance analysis of PCTT and DCTT algorithms, which are reliable and stable platforms based on clustering, was presented to better track the target in the VANET network. The two distributed algorithms were also compared to other centralized target tracking applications [43]. A routing protocol for urban VANET networks called UVANET was proposed in 2017 to improve e2e latency, packet delivery rate, hop count and a number of communication gaps. This protocol sends data packets to the destination in the shortest possible time [44]. Another article was presented in 2017 as a review of the security issues of the VANET network and related issues such as anonymity, integrity, authenticity, availability and non-repudiation to maintain a secure connection between V2I and V2V [35].

In 2018, a fast and secure mechanism for Smart Cities was introduced. In this way, the handoff delay rate is acceptable for ITS software and services that are sensitive to latency. This method also reduces the packet loss rate and leads to increased performance and improved connectivity in V2I communication [45]. An intelligent vehicle decision support system called SIV-DSS was introduced to help decide whether to drive or stop at intersections to reduce the risk of red light crossings and unnecessary stops at intersection areas and improve movement in 2018 [46]. Another article presented in 2018 a stochastic mathematical model to investigate the coverage and modeling of urban mmWAVE microcellular networks in V2I communication [47].

In 2019, a multi-hop clustering model was introduced on V2I to improve inter-vehicle ad-hoc network performance between vehicles in terms of latency and packet delivery rates, and to extend network lifetime. They also used the BFS algorithm to run the graph based on motion rate [48]. A security model called CL-PKS was introduced to reduce computational costs for signature verification and privacy and increase the efficiency of V2I communication in 2019 [49]. Another article presented an authentication signature scheme called ID-CPPA for V2I communication in 2019. This method used one-way hash functions to increase performance and reduce computational overhead and message verification in RSU [50].

In 2008, a protocol called PVR was introduced for V2R communication based on vehicle access to the proxy. This method was carried out with the aim of reducing the competition between vehicles for access to the communication channel in a short time. In this method, proxy vehicle messages are collected from other vehicles and only they send messages to the RSU in their coverage area [51]. In 2011, the authors presented a solution to improve vehicle access to V2R communications and reduce connectivity gaps between the RSU and the vehicle by examining V2R communications performance and 802.11p/WAVE standard capabilities. The mechanism is based on a beacon-based procedure and reduces latency and the number of missing packets [52]. In 2013, a real-time dissemination system for city facilities such as free parking and daily flyers from shops and restaurants was launched for V2R communication. This was done with the aim of improving people's daily lives and reducing the rate of information transmission [53].

In 2016, an analytical model for finding and accessing a service using V2R communication was introduced. This method facilitates the decision to switch to the switch channel based on the type of data exchanged and leads to an improvement in people's daily lives and an improvement in message delivery [54]. In 2017, a vehicle positioning model was proposed to estimate vehicle arrival orientation and arrival time for V2R communication and it performed better than GPS and INS [55]. An article presented a routing protocol using V2R communication based on distributed clustering 2017.

This method used fuzzy logic, reinforcement learning, and game theory to allow vehicles to choose the path that would lead to maximizing network performance [56]. In 2018, a model for secure communication between vehicles and secure communication between the vehicle and the RSU based on V2R and inter-vehicle communication was introduced. This was done with the aim of providing a safety parameter and reducing accidents and traffic congestion [57]. Another model was proposed in 2018 to find and book parking spaces using V2R communication, resulting in a reduction in accidents and improved delivery rates and delays [58].

2.3. Infrastructure to Vehicle Communication (I2V)

Infrastructure-based communication transfers information between vehicles and infrastructure (which includes elements such as cellular base stations, roadside units, traffic lights, etc.) over a longer range through wireless communication. This type of communication is used to handle traffic and avoid bottlenecks [8].

Fig. 5. shows this type of vehicular communication. Roadside units using this type of communication broadcast integrated information about vehicles and RSUs in their communication range to nearby vehicles to be aware of road conditions, weather situations and current traffic congestion, and even to report incidents and accident warnings. Some applications of this type of communication include warning of red light violations, sending warnings to reduce speed on winding roads, warning of information regarding special weather conditions, warning of choosing alternative routes, or stopping large vehicles based on information received from the infrastructure have been localized in tunnels and bridges, warning of violations when crossing railway lines, a system for finding intelligent parking spaces, sending information about speed limits and other information needed for daily activities, leisure activities, etc. [8, 9, 27].

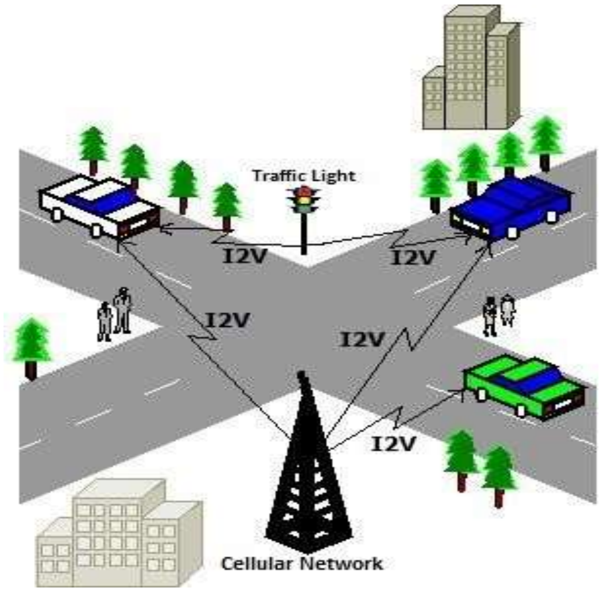

Fig. 5. Infrastructure to Vehicle Communication (I2V)

Summarized below are some research results on the use of I2V communication in different fields to improve the types of intelligent transportation system applications.
In 2007 and 2008, I2V and V2V communication evaluation scenarios based on the 802.11b standard were performed to evaluate the connection time of moving vehicles and to determine the two important factors communication distance and LOS [59, 60].

In 2011, a content download system for I2V and V2V communication was introduced, which solved the max flow problem. This article aims to increase the efficiency of the system, studied the effect of various parameters on the performance of this system and showed that the system is useful in delivering multi-hop traffic [61]. In 2012, a system was introduced to find and reserve parking in urban areas. In this method, they solved the MILP problem and used I2V and V2I communication to send messages between the vehicle and the proposed system [62].

Two vehicle-based and infrastructure-based softwares were introduced in 2012 to reduce traffic at signaled intersections for I2V communications. In this way, they improved traffic lights by receiving vehicle information such as estimated time of arrival and vehicle type to stay green, which in turn reduces traffic volume, air pollution and fuel consumption [63]. Another 2012 article provided a way of authorization and priority control for software on VANET that provides high quality essential I2V services [64]. In 2014, content delivery for vehicular users in WiFi infrastructure was highly analyzed by TCP. They showed that I2V communication over WiFi is useful to deliver large amounts of content to vehicles and users and increase communication time [65]. Another analytical assessment was conducted to examine the ability of VANET networks to offload LTE infrastructure in 2014. Then a participatory traffic transfer algorithm was proposed that makes the decision for offloading based on the parameters such as channel load, V2V connection quality, I2V connection duration and availability of VANET links [66].

2.4. Vehicle Communication to (Vehicle/ Infrastructure/ Roadside unit/ Universe) (V2X)

V2X communication is another type of existing communication in vehicular ad-hoc networks, which plays an important role in the future structure and architecture of intelligent transmission systems. V2X is a wireless technology that aims to increase the level of drivers and road safety, and also improve road traffic management and monitoring, thereby reducing the environmental impact. As shown in Fig. 6., the V2X term is a combination of V2V, V2I, V2R, and V2U communications (the character of U in V2U means the universe that includes satellite, grid, public security, GPS, pedestrian, cloud services, home, etc.). V2X can leverage the above communication capabilities and combine them with Wi-Fi, LTE and DSRC technologies. V2X communication facilitates communication and transmission of useful information between the vehicle and infrastructure/ pedestrians/devices/or other things that may affect the vehicle using the above technologies [3, 9, 27, 67].

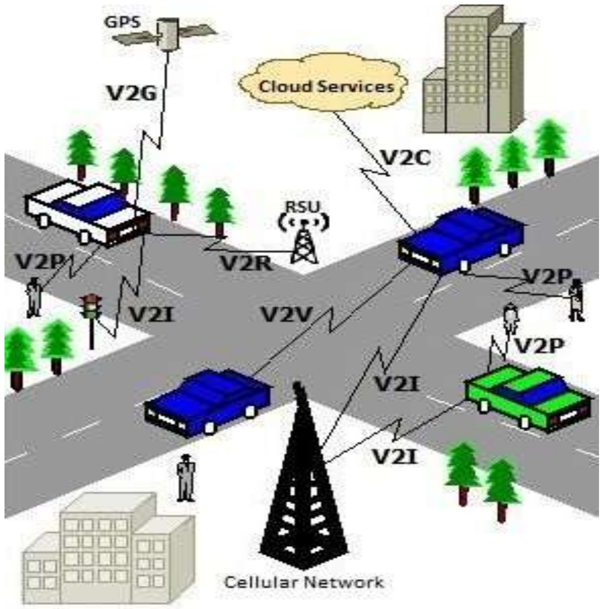

Fig. 6. V2X Communication

The components of V2X communication include the following elements [67]:

- Vehicles
- Pedestrian
- Roadside Unit
- Cloud services
- Global Positioning System (GPS)
- Satellite
- Cellular Networks
- Traffic lights and...

Various applications have used this type of communication in different fields, some of which can be mentioned: incident management, accident prevention, road situation, and traffic monitoring, passenger entertainment programs such as online games, as well as driver convenience applications such as finding a suitable restaurant at the new city or the Finding a parking space and so on [67]. The summary of some work done with V2X communication in different areas is reviewed as follows.

In 2009, the authors introduced a concept called snapshot to record the spatial and temporal information of vehicular users. Then they proposed a numerical measure to measure the level of vehicle location privacy in the V2X communication system [68]. In 2013, an analysis of the impact of different levels of privacy of V2X communication on accident avoidance systems at intersections was presented by analyzing different traffic scenarios at intersections [69]. In 2015, a new architecture for V2X communication called V2X-d was introduced to determine traffic levels in road traffic. This architecture uses two types of communication, V2V and V2I, and estimates traffic levels based on information collected from sensors and road topology information [70]. A clustering method for data delivery in the VANET network using neighbor stability for V2X communication was proposed in 2015. The proposed NSVC method handles network topology changes and ensures reliable data delivery for important messages [71].

In 2016, a road condition information sharing system was introduced to reduce accidents using V2X communication. In this article, the authors estimated the WiFi communication range for sharing information without an internet connection [72]. In 2017, an article examined the various security issues and challenges that pose a threat to sensing in V2X communications, and presented V2X services along with privacy, authenticity, and confidentiality [67]. Another paper presented a security credential management system for V2X communication in 2017. This model is used to create a nationwide public key infrastructure to provide security and privacy for V2X communications and to support misconduct reporting, revocation, bootstrapping and certificate deployment [73]. Another 2017 article proposed a predictive routing protocol for V2X communications called PRHMM. Based on the Hidden Markov Model, this model improves transmission performance based on vehicle behavior and leads to a reduction in latency, traffic volume and improved delivery rates [74].

Another paper designed a communication architecture using three different communication groups of V2X in the off-road environment for finding a sustainable communication architecture for the proper involvement of V2X communication components in 2017 [75]. In 2018, a review article examined the advantages of cellular infrastructure for this type of communication, in addition to the introduction of V2X communication in VANET networks and the types of services and security requirements in this system. Then describes the architectural types of cellular-based V2X systems and the research challenges of these systems [76]. SDN-based application layer scheduling was proposed in 2017 for the simultaneous use of LTE and WiFi in V2X communication. A heuristic algorithm in V2V and V2I communication was then used to allocate the resources to maximize the quality of the system experience and reduce the computational complexity [77]. A 2017 article provided an overview of the various systems, applications and research related to V2X communications. This article also discusses the advantages and disadvantages of the different technologies used for V2X communication [78]. Another architecture for V2X communication based on content-centric networking was introduced in 2017. CCN with optimized routing and proactive caching in this architecture can perform better than conventional reactive content caching methods [79]. In 2018, a secure method was introduced for protecting vehicle location in V2X communication using CBDG algorithm together with TTP. With this algorithm, before sending the query to TTP, several fake locations are first created by the BCDG algorithm in order to reduce the computing and communication effort in addition to protecting privacy [80].

After examining the related work with VANET communication, we categorized them in terms of driver and road safety, passenger entertainment and driver convenience, development of communication structure, achievement of system QoS, improvement of traffic congestion, reduction of delay in data transmission, increase of Packet Delivery Rate (PDR), improving computational and communication costs in table 1.

Table 1
Categorization of related works on VANET communication based on various parameters

Ref	Type of Communication	Driver and road safety	Passenger entertainment and driver convenience	Development of communication structure	Achievement of system QoS	Improvement of traffic congestion	Reduction of delay	Increase of PDR	Improving computational costs	Improving communication costs
[5]	V2V		✓			✓		✓		
[7]	V2V		✓		✓		✓			✓
[8]	V2V	✓			✓		✓	✓		
[10]	V2V			✓	✓		✓			✓
[11]	V2V			✓				✓		✓
[13]	V2V	✓						✓	✓	
[14]	V2V	✓			✓		✓	✓		
[15]	V2V	✓			✓		✓	✓		
[16]	V2V			✓	✓	✓	✓	✓		
[17]	V2V			✓		✓	✓			✓
[18]	V2V			✓	✓	✓		✓		
[19]	V2V			✓	✓	✓	✓			
[20]	V2V			✓		✓	✓	✓		
[21]	V2V			✓	✓		✓	✓		
[22]	V2V	✓						✓	✓	✓
[23]	V2V		✓			✓	✓	✓		
[24]	V2V		✓				✓	✓		
[25]	V2V	✓			✓	✓				
[26]	V2V	✓					✓	✓		
[27]	V2V		✓		✓	✓				
[28]	V2V	✓						✓		✓
[29]	V2V		✓		✓					✓
[30]	V2V		✓		✓			✓		✓
[31]	V2V			✓			✓	✓		✓
[32]	V2V			✓		✓	✓	✓		
[33]	V2V			✓			✓	✓		✓
[34]	V2V		✓				✓	✓		
[35]	V2I	✓				✓		✓	✓	✓
[36]	V2I			✓		✓		✓		✓
[37]	V2I	✓					✓			
[38]	V2I	✓			✓			✓		
[39]	V2I	✓			✓		✓	✓		
[40]	V2I			✓	✓		✓		✓	
[41]	V2I	✓			✓			✓		
[42]	V2I			✓	✓		✓			
[43]	V2I			✓	✓		✓	✓		
[44]	V2I		✓				✓	✓		✓
[45]	V2I		✓		✓		✓	✓		
[46]	V2I		✓		✓	✓				
[47]	V2I			✓	✓	✓			✓	
[48]	V2I			✓	✓		✓	✓		
[49]	V2I	✓					✓		✓	✓
[50]	V2I	✓			✓	✓			✓	
[51]	V2R			✓	✓					✓

[52]	V2R	✓			✓		✓	✓		
[53]	V2R		✓		✓			✓		
[54]	V2R		✓		✓			✓		
[55]	V2R		✓				✓	✓		
[56]	V2R		✓		✓	✓				
[57]	V2R	✓				✓	✓			
[58]	V2R		✓				✓	✓		
[59]	I2V			✓			✓			✓
[60]	I2V			✓			✓			✓
[61]	I2V		✓		✓			✓		
[62]	I2V		✓			✓			✓	
[63]	I2V		✓			✓				✓
[64]	I2V		✓				✓	✓	✓	
[65]	I2V			✓				✓		✓
[66]	I2V			✓	✓					✓
[67]	V2X	✓			✓	✓				
[68]	V2X	✓			✓					✓
[69]	V2X	✓					✓	✓		
[70]	V2X		✓			✓			✓	
[71]	V2X	✓			✓		✓	✓		
[72]	V2X		✓		✓					✓
[73]	V2X	✓					✓			✓
[74]	V2X		✓			✓	✓		✓	✓
[75]	V2X			✓			✓	✓		✓
[76]	V2X	✓				✓			✓	✓
[77]	V2X		✓		✓				✓	
[78]	V2X			✓	✓	✓				
[79]	V2X		✓				✓	✓		
[80]	V2X	✓					✓		✓	✓

3. Challenges and Research Aspects

According to the given explanations on the vehicular ad-hoc network and the types of communication in this network, as well as after reviewing various articles in this area, to design more effective communication methods in VANET networks, challenges and research topics can be mentioned that it is necessary to address and solve. We have divided these issues into several categories:

- Issues related to VANET network dynamics: Due to the high speed and movement of vehicles and the nature of information propagation models, vehicular ad-hoc networks are wireless channels where the network environment and topology are constantly changing. So this network is divided into some subnets. These subnets are clusters of network nodes where the interaction between these clusters is considered an important issue and should be addressed in order to establish effective communication between network components. Due to the movement of network nodes and their insufficient number in low-traffic environments, such as rural environments, the problem of network fragmentation and disconnection is another problem that leads to a lack of access to network nodes. On the other hand, in addition to the lack of a sufficient number of vehicles and nodes in the network in low-traffic environments, not all vehicles are equipped with transceivers, leading to this problem. In such cases, in order to achieve effective communication and increase network efficiency, the network needs communication protocols that are aware of the disruption in communication, which should also be addressed and solutions proposed. Also, the movement pattern of vehicles due to the characteristics of roads and their high speed leads to problems such as very short-term communication between network components, frequent interruption of communication link, delay and loss of communication link bandwidth, continuous data collision, and communication channel fading and so on. These issues should also be addressed to better transfer data between network components.

- Reliability issues: Another existing issue in the VANET network that needs to be addressed is the reliability issue required to achieve efficient network communication through judicious use of media between vehicles and network infrastructures.
- Issues related to multi-hop routing and multi-hop wireless channels: Proper network performance has a significant impact on the availability of communication channels, which is common with a large number of network nodes. Adaptability to frequent network topology changes is also essential. Therefore, timely and appropriate transmission of messages and effective communication between network nodes requires the design of efficient multi-hop protocols to control access according to the type of usage and the type of network. This leads to the prevention of data collisions and errors, especially in environments where network traffic is high and there are problems such as data collisions and the occurrence of data transmission errors. Addressing issues associated with multi-hop connections, which include the reliability and performance of communication channel access control protocols, is also essential to increasing the effectiveness of network communications.
- Issues related to network scalability and accessibility: Due to a large number of mobile and fixed nodes in the network, as well as frequent changes in network topology, the network must be scalable. On the other hand, large VANET networks must be able to manage themselves and even split into subnets to increase network performance and automatically configure themselves properly despite the problem of lack of confidence in proper communication existence. Also in large VANET networks there is a discussion about the management and storage of generated data in the network and new plans for the management, storage and distribution of this data are needed.
- Issues related to interaction with other networks: In order to get useful information for drivers and passengers, drivers must be able to communicate well with other vehicles, applications, pedestrians, etc. on other networks. This information can be accessed over the Internet, sensor networks, and other wireless technologies. Therefore, creating compatible communication protocols with a variety of technologies for effective and better transfer of information between network components is one of the issues that need to be addressed. Also, the standardization of communication protocols for effective communication between mobile network nodes (including cars, buses, motorcycles, trucks, etc.) is another topic that can be addressed in the future.
- Issues related to security and privacy: VANET networks, by their nature, are vulnerable to security attacks. To ensure reliability, authentication, information accessibility, and integrity, the VANET network requires secure communication protocols and appropriate security designs and architectures that can detect and handle internal and external attacks to allow network nodes to interact and transmit information to each other.
- Routing-related issues: Since communication between network components is often lost, appropriate protocols and algorithms are required for effective and reliable routing between network nodes according to network conditions. In addition, in order to carry out the communication process for effectively sending information, the physical location of network nodes is required, which is one of the most challenging problems at present.

4. Conclusion

Communication in vehicular ad-hoc networks is one of the most important and important issues in this network, which is used to send information between network components with the goals of road traffic management, increasing the safety level of users and roads, passenger comfort, and improving efficiency. In this article, we first examined the types of communication in the VANET network and divided them into four main categories: V2V, V2I, I2V and V2X. We then briefly summarized the work done in this area. Then these works were classified and presented in a table based on the purposes of driver and road safety, passenger entertainment and driver convenience, development of communication structure, achievement of system QoS, improvement of traffic congestion, reduction of delay in data transmission, increase of Packet Delivery Rate (PDR), improving computational and communication costs. Finally, the challenges and research topics to achieve effective communication in the VANET network were presented.

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