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PAPER

Exploring the Potential and Challenges of Vehicular Ad Hoc Networks: A Comprehensive Review

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ABSTRACT

The paper discusses the architecture of vehicular ad hoc networks (VANETs) and their applications, simulation tools, communication domains, and challenges. VANETs enable wireless communication between moving vehicles using dedicated short-range communication (DSRC) technology, and vehicle-to-infrastructure communication with roadside units. The paper describes the three main components of VANETs: the roadside unit (RSU), application unit (AU), and on-board unit (OBU). The purpose of the paper is to provide researchers and developers with detailed information about VANETs and help them understand their aspects and challenges. The information provided in the paper could facilitate the development of VANETs for enhancing road safety and providing comfortable driving experiences.

KEYWORDS

vehicular ad hoc networks, on-board unit, roadside unit, application unit

1 INTRODUCTION

Information and communication technology has played a significant role in driving major innovations in the automotive industry and society as a whole. The introduction of mobility has transformed our lifestyles, enabling us to access information from anywhere, at any time. In the near future, automobiles will be equipped with mobile communication systems, as depicted in Figure 1, which illustrates the VANET communication model [1]. The development of intelligent transport system (ITS) has become a crucial component of smart cities, thanks to the emergence of information and communication technologies (ICTs) and wireless embedded sensing devices. The use of infotainment is now employed to enhance traffic efficiency, improve safety, and provide valuable information [2], [3]. Despite having excellent quality and sharing some similarities with mobile ad hoc networks (MANETs), such as comprising mobile vehicles, a VANET possesses certain unique characteristics [4], [5]. In recent years, the automotive industry, academic institutions, and government agencies have been collaborating more closely to promote vehicular communication

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on a broader scale [6], [7]. Many VANET research projects and standardization initiatives have been conducted worldwide because of the significant potential offered by VANETs. One of these initiatives is the Vehicle Safety Communications Consortium (VSCC), a project co-funded by the European Automotive Industry and the European Communications Commission (ECC), aimed at developing the dedicated short-range communication (DSRC) system [1].

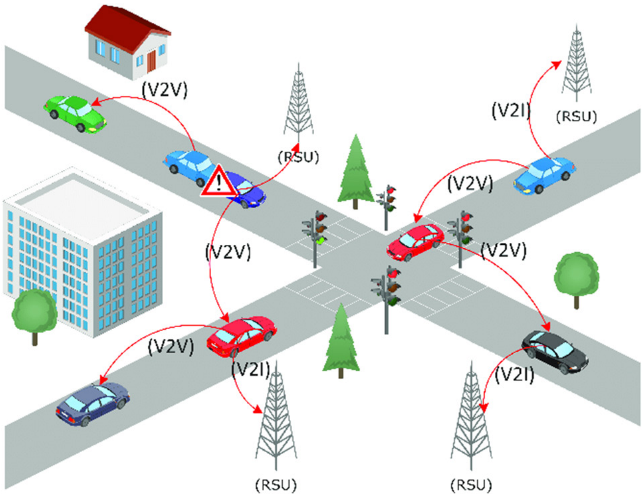

Fig. 1. VANET communication model [13]

VANETs enable mobile vehicles to communicate wirelessly using DSRC, which is an IEEE communication standard that ranges from IEEE 802.11a for low overhead operation to 802.11p. In a VANET, vehicles can establish communication with each other, known as vehicle-to-vehicle (V2V) communication, as well as with fixed units positioned along the road, known as roadside units (RSUs), which come under vehicle-to-infrastructure (V2I) communication. These categories of communication enable vehicles to share various types of information, such as traffic congestion, safety information for avoiding accidents, and post-accident investigation. They can also share non-safety-related information, such as weather conditions and commercial services along the route. The purpose of sharing and disseminating this information is to provide drivers with safety messages, alerting them to potential hazards, thereby reducing accidents, saving lives, and providing passengers with a comfortable and enjoyable ride.

This paper provides a crucial resource for researchers and developers, as it contains comprehensive information on the key features and challenges related to VANET. It covers various topics, including communication domains, network architecture, applications, challenges, and simulation tools. The information presented in this document will help researchers and developers gain a better understanding of VANET and facilitate the development of innovative solutions in this field [8]–[10].

2 VANET ARCHITECTURE

WAVE refers to a type of wireless communication used for exchanging data between vehicles and also between an RSU) and a vehicle. Apart from offering drivers and passengers various types of information, this mode of communication also enables safety applications to provide a convenient driving experience and promote road safety [1]. The terms "provider" and "user" are used to describe distinct entities, with the provider being responsible for delivering services and the user consuming them. In the context of networks, both RSUs and OBUs can take on the roles of either provider or user based on their functions within the network [8]. A system includes three major elements: an RSU, an application unit (AU), and an OBU [4]. VANET architecture is shown in Figure 2.

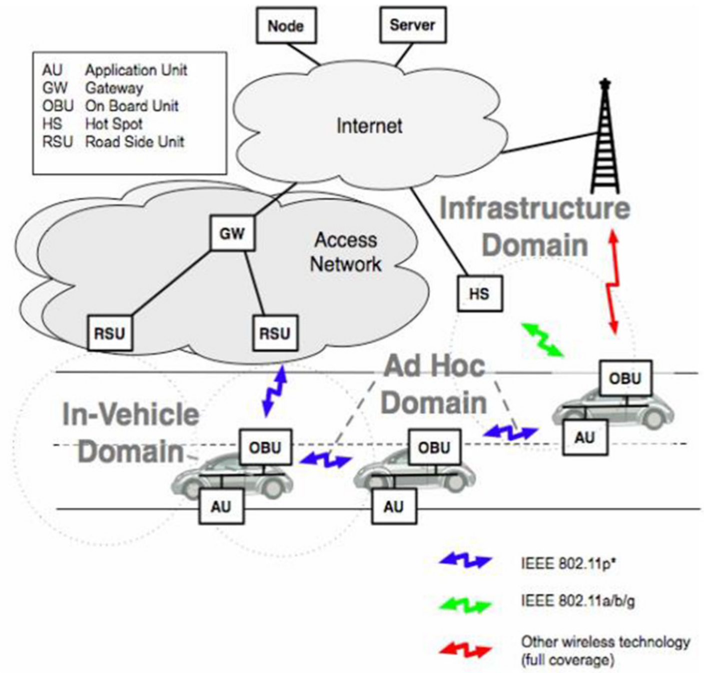

Fig. 2. Architecture of C2C-CC reference [28]

A. The OBU is a vehicle-tracking device that is GPS based and present in most vehicles. It transmits data to RSUs and other OBUs. The OBU includes electrical components such as user interface, resource-control processors (RCPs), sensing devices, data storage, and read/write storage. The main function of the OBU is to build a wireless link through IEEE 802.11p with either an RSU or another OBU and communicate with them by exchanging messages. The OBU utilizes power from the automobile's battery for its operation. In addition, every vehicle has sensors such as GPS, forward and backward sensors, and an electronic data recorder (EDR), which transmit data to the OBU [13].

B. An RSU is a computer device positioned along a roadside or at a designated location such as an intersection or parking lot. Its purpose is to establish a local communication that connects with passing vehicles. The RSU is typically composed of network devices based on IEEE 802.11p radio technology, which is specifically designed for 1000 m communication through DSRC. RSUs can be utilized to link a specific network device that is a component of other network infrastructure [13] [15].

C. An AU is an apparatus placed within a vehicle and utilized in combination with the service provider's application for exchanging messages with the OBU. Apart from safety applications, the AU can also be operated using a standard device such as a personal digital assistant. The OBU is linked to the AU through a wireless or wired medium. It supplies the OBU with the ability to connect to the internet, allowing for the transfer and receipt of information [1], [11].

2.1 Primary elements of VANETs

According to the ISO/IEC 42010 and IEEE 1471–2000 standards, the elements of VANETs are categorized into three domains:

- The generic domain encompasses the private infrastructures and internet.
- The mobile domain encompasses mobile devices and vehicle domains. Vehicles include buses, cars, and trains, while mobile devices encompass portable devices, such as laptops, smartphones, and smartwatches.
- The infrastructure domain comprises the roadside infrastructure domain, which includes traffic lights, cameras, and other similar equipment in the domain of central infrastructure, which includes vehicle management and centers of traffic management [3].

  The standard for VANET architecture in Europe is slightly distinct from others and is based on the system of CAR-2-X communication, which is being developed by the CAR-2-CAR Communication Consortium. This system's reference architecture, illustrated in Figure 2, consists of several domains, including [3]:
- Ad-hoc domain is made up of vehicles that have stationary RSUs and OBUs located at certain points along the road. OBUs can connect with each other using wireless short-range communication devices, either directly or through multi-hop communication. This allows for ad-hoc communication between vehicles. An RSU is a stationary device that can be connected to an infrastructure network or the internet. It can send, receive, or forward data in the ad-hoc domain (i.e., vehicles with RSUs and OBUs), which extends the coverage of the ad-hoc network. An OBU can access the internet through an infrastructure-connected RSU, public commercial or private wireless hotspots (HSs) to communicate with internet nodes or servers.
- In-vehicle domain refers to a collection of devices that include an OBU and one or more (AUs). An AU is a specialized device that can be either a separate portable device, such as a smartphone or laptop, or a part of a vehicle. The OBU runs one or multiple applications that utilize its communication capabilities. Both the OBU and AUs remain connected to each other constantly through either a wired or wireless connection.
- Infrastructure domain refers to the collection of HSs and RSUs. In cases where HSs or RSUs offer internet access, OBUs can take advantage of cellular radio networks such as WiMAX, 4G, 5G, and HSDPA.

2.2 Architecture of communication in VANET

The communications in VANET are categorized as follows [13]:

- In-vehicle communication refers to the communication that occurs between a vehicle's OBU and its AUs.

- Vehicle-to-vehicle (V2V) refers to wireless communication that occurs between two vehicles using their respective OBUs.
- Vehicle-to-infrastructure (V2I) refers to two-way wireless communication that occurs between a vehicle and RSUs that are connected to infrastructure.
- Infrastructure-to-infrastructure (I2I) is wireless communication that occurs between RSUs, which extends the network coverage.
- Vehicle-to-broadband cloud (V2B) is wireless communication between broadband cloud and a vehicle using wireless broadband technologies, such as 3G, 4G, and 5G.

3 CHARACTERISTICS OF VANET

VANETs exhibit unique behavior and characteristics that distinguish them from other networks:

3.1 High mobility

VANETs operate in highly dynamic environments, where traffic density can vary significantly during peak hours and vehicles can travel at varying speeds. VANETs consist of fixed roadside units and mobile vehicles. At 80 km/h, the varying velocities of vehicles can pose communication challenges [11], [12]. When traffic is congested, vehicles have more time to exchange messages due to the slowdown or stoppage of traffic.

3.2 Predictable mobility

Vehicle movements can be predicted on roadways, as these provide designated routes for vehicles. GPS technology facilitates the acquisition of data about roads, and a vehicle's location can be readily determined by analyzing its path and speed as it travels on the road [14].

3.3 Network topology and connectivity

As vehicles move around, the network topology is continually changing. This means that the connections and disconnections between nodes are frequent occurrences and contribute to the dynamic nature of the network topology.

3.4 The availability of power resource

The power availability is not a problem in VANETs because the vehicles are equipped with robust batteries that continuously supply power to the OBUs. This has allowed for the creation of a network that can transmit information from one vehicle to another without the need for excessive energy or computational resources. Moreover, vehicles in VANETs are equipped with powerful computers that are capable of processing complex calculations.

3.5 Inconsistent network solidity

The network stability of VANETs can be inconsistent due to variations in traffic density. For instance, network density can differ in urban areas, highways, and rural areas, which can impact the stability of the network. Rural areas tend to have lower accident rates compared with urban areas and highways.

3.6 High computational facility

VANETs include efficient sensors, high-memory capacity, internet access, advanced antenna technology, General Packet Radio Services (GPRS), and storage space. These features have significantly improved the computational power of vehicles [11].

4 REQUIREMENTS AND CHALLENGES IN VANET

The use of ad hoc networks is being employed to enhance driver behavior and ultimately lower traffic fatalities. The VANET concept is complex and necessitates meticulous consideration of several factors, including safety and non-safety applications, which have a significant influence on achieving the primary objective [1].

4.1 Signal loss

When two vehicles are in motion and communicating wirelessly, signal loss can occur. Obstacles such as buildings or other vehicles can present challenges to the wireless connection. These obstacles can lead to signal fading, which in turn can affect the efficiency of communication in VANETs.

4.2 Bandwidth

In VANETs, there is no access point or central monitoring to collect and transmit information. Therefore, each node must utilize the available bandwidth to optimize its performance. This can be challenging due to bandwidth constraints in the VANET environment.

4.3 Connectivity

The network topology of VANETs is continually changing, which can result in network fragmentation, potentially reducing efficiency and increasing response times.

4.4 Privacy and security

One of the major obstacles in VANETs is achieving an appropriate balance between privacy and security; specifically, ensuring that only authorized individuals can transmit information and that recipients can trust the messages they receive.

5 VANET APPLICATIONS

Based on [3], VANET applications are divided into four categories: safety and non-safety applications, traffic efficiency applications, and comfort applications. Table 1 highlights some of the most practical applications of VANET.

5.1 Safety applications

The three primary safety applications of VANETs are alert information, driver assistance, and warning alerts. The VSCC has identified eight additional possible safety applications for VANETs, including curve speed measurement, pre-crash detection, lane-change assistance, emergency electronic brake lights, traffic signal violation detection, stop sign movement detection, and assistance with left turns. To decrease the number of fatalities and road accidents, it is essential to implement significant road safety applications on highways. These applications offer drivers critical traffic information in real time, which enables them to avoid accidents with other vehicles and potentially saves lives

5.2 Non-safety-related applications

VANETs can provide non-safety-related services, such as comfort or commercial services, which can enhance advertising effectiveness, passenger comfort, and traffic efficiency as well as enable electronic toll collection. These services can include identifying traffic congestion, weather conditions, and other important points such as gas stations, hotels, parking lots, malls and fast-food restaurants. However, using VANETs for comfort and commercial applications is believed to be harmful to traffic efficiency and safety, as it can distract drivers and interfere with safety services.

5.3 Efficiency applications

The efficient applications of VANETs aim to improve the movement of vehicles within city lanes by identifying their location and optimizing their routes. This involves communication between vehicles and RSUs. These applications can be divided into two categories: road and crossing management and traffic reduction [3].

5.4 Comfort applications

Refer to software programs that offer drivers information to enhance their travel experience and convenience. Such applications can include data on weather conditions, gas stations, available parking spaces, and restaurant locations, among other features [1]. These applications are designed to make travel more enjoyable and user-friendly for drivers, as shown in Table 1.

Table 1. Practical applications of VANETs

Application Type	Benefit	Description
System of cooperative collision avoidance	Enables communication between vehicles to avoid collisions	The system uses various communication technologies to detect and avoid collisions, such as radar, lidar, and GPS. Researchers proposed a cooperative collision avoidance system that uses VANETs to enable communication between vehicles to avoid collisions. The system was tested in a simulation environment and showed promising results in reducing the number of collisions and improving road safety [16].
Entertainment and infotainment services	Provides streaming music and video services to drivers and passengers	The system is designed to enhance the driving experience, reduce boredom, and improve passenger satisfaction. Researchers proposed a VANET-based entertainment and infotainment system that provides streaming music and video services to drivers and passengers [17].
System for parking management	Provides real-time information about available parking spaces to drivers	The system is designed to decrease traffic congestion, improve parking efficiency, and enhance the driving experience. Researchers proposed a system for parking management based on VANET, which can offer drivers with up-to-date details about the availability of parking spaces. The system uses wireless sensors and VANETs to detect and communicate parking space availability to drivers [18].
System for traffic sign recognition	Uses cameras and image processing techniques to recognize traffic signs and provide real-time information to drivers	The system is designed to improve road safety and reduce accidents by providing drivers with up-to-date information about road signs. Researchers proposed a VANET-based traffic sign recognition system that uses cameras and image processing techniques to recognize traffic signs and provide real-time information to drivers [19].
System for autonomous vehicle control	Helps autonomous vehicles to communicate with other vehicles and infrastructure to avoid collisions and enhance traffic efficiency	Researchers proposed a VANET-based autonomous vehicle control system that uses V2V and V2I communication to enable autonomous vehicles to communicate with each other and with traffic-management centers [20].
System for emergency vehicle warning	Helps emergency vehicles to communicate with infrastructure and other vehicles to clear the way and improve response time	Researchers proposed a system for emergency vehicle warning based on VANET that uses V2V and V2I communication to detect and communicate the presence of emergency vehicles to other drivers [21].
System for traffic congestion management and detection	Uses real-time traffic data and predictive analytics to detect and manage traffic congestion	Researchers proposed a VANET-based traffic congestion detection and management system that uses vehicle-to-infrastructure communication to collect and analyze real-time traffic data [22].
Intelligent intersection management system	Uses real-time traffic data and machine learning algorithms to optimize traffic flow at intersections	Researchers proposed a system for intelligent intersection management based on VANET that uses V2I communication to collect and analyze real-time traffic data and machine learning algorithms to optimize traffic flow [23].
System for eco-driving support	Helps drivers to reduce fuel consumption and emissions by providing real-time information about traffic conditions and road topology	Researchers proposed a VANET-based eco-driving support system that uses V2V and V2I communication to collect and analyze real-time traffic data and road topology information. The system was tested in a simulation environment and showed promising results in reducing fuel consumption and emissions [24].
Intelligent speed limit control system	Offers drivers up-to-date traffic and road condition information, allowing them to drive at a safe and suitable speed.	Researchers proposed a VANET-based intelligent speed limit control system that uses vehicle-to-infrastructure communication to collect and analyze real-time traffic data and road conditions. The system was tested in a simulation environment and showed promising results in reducing the risk of accidents and improving safety [25].
Intelligent emergency braking system	Helps to prevent collisions and reduce the severity of accidents.	Researchers proposed a VANET-based intelligent emergency braking system that uses vehicle-to-vehicle communication to detect potential collisions and apply brakes automatically if necessary. The system was tested in a simulation environment and showed promising results in reducing the severity of accidents [26].
Intelligent vehicle routing system	Helps to optimize vehicle routing and reduce travel time and fuel consumption	Researchers proposed a VANET-based intelligent vehicle routing system that uses V2V and V2I communication to collect and analyze real-time traffic data and road conditions. The system was tested in a simulation environment and showed promising results in reducing travel time and fuel consumption [27].

6 CONCLUSION

The paper provides a detailed overview of VANET applications, communication domains, architecture, simulation tools, and challenges. It provides researchers and developers with comprehensive information about VANETs and helps them understand its aspects and challenges. The three main components of VANETs—OBU), (AU), and RSU—are described in detail. The paper concludes that VANETs have the potential to improve road safety and provide comfortable driving experiences, and the information provided in the paper could facilitate the development of VANETs.

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