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Mobile Vehicular Networking Systems / VANETs: Structure, Challenges, Routing, and Future Developments: A Review

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ABSTRACT: The Vehicular Safety Consortium (VSC), the Crash-Avoidance Metrics Partnership (CAMP), and the Vehicle Infrastructure Initiative (VII) are working beside leading light-duty vehicle manufacturers to develop safety technology and applications for "Vehicular ad-hoc Networks". "VANETs" are poised to alter the future of transportation by enabling the real-time communication between vehicles (V2V) and vehicles to infrastructure (V2I). These networks are critical for increasing road safety, regulating traffic flow, and enabling the development of self-driving technologies. This paper provides a thorough examination of VANETs' fundamental architecture, outlining multi-layered communication protocols, incorporation of cellular networks such as 4G/5G, and their ways of use to improve these services. The paper also investigates the architecture of VANETs built to solve the unique challenges of automobile environments, such as high mobility, intermittent connectivity, and rapid topological change. It examines the scalability of VANETs in densely populated metropolitan regions, emphasizing the inadequacies of present protocols and proposing improvements through advances in wireless technologies and complex routing-algorithms. The paper predicts future developments of VANETs, particularly the combination of emerging technologies such as edge and cloud-computing, Internet of Things (IoT), and AI-enhanced traffic management systems. Furthermore, the growing significance of autonomous vehicles within VANET frameworks emphasizes the importance of seamless vehicle coordination and infrastructure improvement to enable self-driving cars. This paper contributes the discussion about the evolution of VANETs to meet the needs of more innovative, safer, and more efficient transportation systems, highlighting potential impact on global mobility trends.

Keywords: VANETs, VSC, CAMP, DRG, ROVER

1. INTRODUCTION

The frequency of accidents has grown in tandem with the proliferation of moving nodes (cars) on the road. The "National Highway Traffic Safety Administration" (NHTSA) reports of 2.7 million more people are injured every year and that 43,000 people die in traffic-related incidents. The societal cost is over $230 billion [1]. Improving the AI of our cars is crucial if we want to minimize the frequency of incidents. The flexibility afforded to the drivers and users, the access to data from anyplace, the ease of deployment, and more services are the mainly reasons for its meteoric rise. Spontaneous ad-hoc communicate networks are made up of mobile stations (nodes) that are positioned close together and communicate with each another, exchanging supports, resources, or computing time for a short amount of time and in a kind of small-area [2]. Autonomous vehicles can do more with the help of a VANET. Established and approved protocols for the physical (PHY) and medium access control (MAC) layers of vehicle networks are IEEE 802.11p Wireless Access for Vehicle Environment (WAVE) and Dedicated Short-Range Communications (DSRC). With a range of about 1000 m and a bandwidth of 75 MHz, the 5.9 GHz DSRC spectrum band is the foundation of the IEEE 802.11p WAVE standardization process [3]. Working jointly, DSRC and the IEEE 802.11p WAVE standard intend to define best practices for immediately identifying networks, reducing connection setup times, and distinguishing between routine and emergency applications of wireless networks. They enable quick transfers with low latency,

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enabling for efficient communication between vehicles. Therefore, there's an improvement in the efficacy of emergency communications [2]. To explain the point, in the case of an accident, messages sent between vehicles can be timelier more efficient than those sent out via an infrastructure network.

Vehicular Ad-hoc Networks (VANETs) are nothing new, but they do bring new challenges to the field of research. The primary objective is to make it easier for multiple vehicles to connect and stay connected through a shared network, all without the need for a single controller or base station. In extreme medical emergencies, when time is of the essence and there is no preexisting infrastructure to transfer data, VANET is frequently employed. However, new challenges and problems emerge alongside these advantageous VANET applications [1]. The inadequacy of the infrastructure places extra burdens on vehicles. Every vehicle joins the network and takes charge of its own communication requirements as well as the network's internal communication management & control [3].

Ad-hoc networking which allow automobiles to contact & communicate between and with one another in a specific setting are known as vehicular ad hoc networks. In "vehicle-to-vehicle" (V2V) communication, two vehicles can talk to each-other directly, while in vehicle-to-infrastructure (V2I) communications, a node (vehicle) talks to an RSU or some different type of infrastructure. Figure 1 [4] below shows a typical VANET setup.

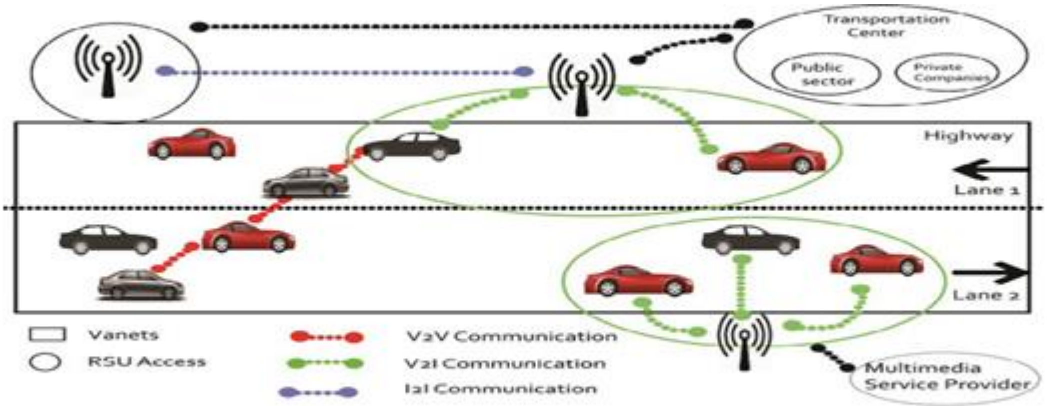

FIGURE 1 VANET Configuration

The most important thing this study has done is to show some of the new stuff in VANET technology. This paper's detailed analysis of network architecture covers a wide range of topologies and models. Establishing a dependable communication network through appropriate packet routing is an essential component of VANET architecture. The paper examines various VANET routing methods and demonstrates their shortcomings. It also aims (targeted) to provide a study of the important security challenges in VANET environment. The paper also highlights several notable research areas and obstacles in the subject.

In general, the paper's organization has later on 14 sections start with an overview of VANET and Intelligent transport system, then go deeply in the background of this research filed, exploring some related works and the differences from this paper (contributions). The characteristics of VANETs are explained in the 4'th section followed by the description of the VANET structures. VANET applications are listed in section 6. Section 7 intensively describes the network mobility and structure. Key researches and challenges are explained in section 8 and 9. Routing protocols in section 10 describes the categories of routing protocols in VANETs (table & figure). Security and privacy are followed in section 11. IoT application & routing in VANETs are briefly explored in sections 12 & 13. Section 14 is specific to wireless technologies in VANETs (a comparison). Conclusions and future suggestions are clarified in the 15'th section.

2. A REVIEW ABOUT VANETs

In VANETs, automobiles are outfitted with wireless sensors and "On-Board Units" (OBUs) to permit communication remotely (wire-less) between the moving nodess (cars) and their surroundings. Those gadgets enable each automobile to function as a packet sender, receiver, and router, allowing it to communicate with other vehicles or RSUs within its range wirelessly. These wireless sensors, OBUs, or radio interfaces allow vehicles to create short-range wireless ad-hoc networks [5]. These networks are used to transmit data to vehicular networks or transportation agencies/authorities. The data is then processed and utilized to improve traffic efficiency and safety on motorways. Vehicles equipped with VANET technology are installed with suitable hardware that enables the collection and analysis of location data, such as those obtained from a GPS or "differential global positioning system" (DGPS) receiver [3][5].

The stationary Roadside Units (RSUs) usually linked to the leading network and strategically placed along the highways to facilitate efficient, dependable, and prompt communication between vehicles [2]. Network devices installed in roadside units enable specialized short-range (short-domain) wireless communication through the use of IEEE 802.11p radio technology. Innovative (intelligent) transportation systems (ITS) offer a variety of possible topologies for vehicular communication, including V2V, V2I, and AP/Internet communication (Figure 2) [6].

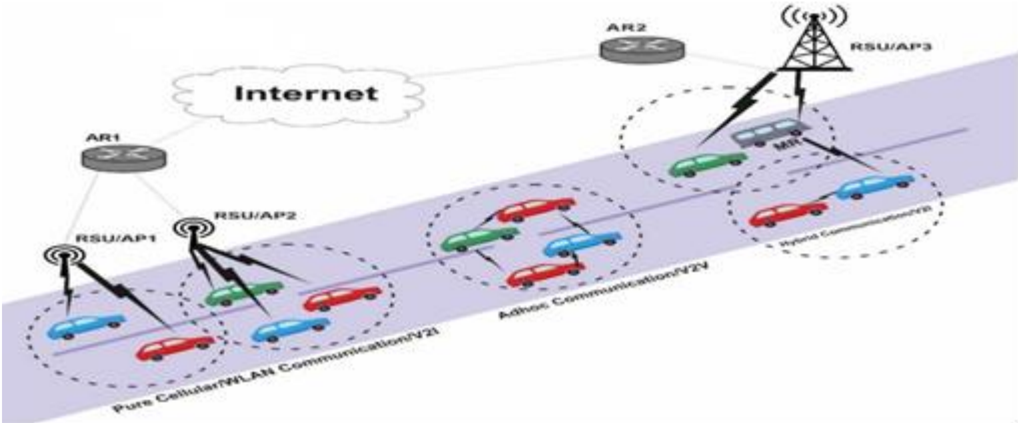

FIGURE 2 **VANET & ITS**

Vehicles can establish wireless contact with each other, known as V2V communication, or with fixed Roadside Units (RSUs), known as V2I communication. The effectiveness of these vehicular communication configurations depends greatly on obtaining precise and current kinematic data for both nodes (vehicles) and the environment in the surroundings. The utilization of location systems, sophisticated wireless protocols of communication, and access-technologies does this by guaranteeing the delivery of accurate, efficient, and timely data. VANETs rely on intelligent cross-layer communication protocols to ensure the rapid and dependable transfer of data packets to all infrastructures and vehicles within its coverage. Reasons for this include the network's limited bandwidth and the medium's unreliability and shared nature [7].

3. BACKGROUND OF THE RESEARCH

An essential design side of VANET is to promote a secure, efficient, and reliable routing protocol. Enormous research had been widely proceeded in this area [1-14].

A "VANET" should be able to fulfill all the requirements of the ever-changing user that is needed and should also comply with the standards and architectures of the updated available technology. Part of the key features of VANETs can be concise as follows (more details below in the VANET Applications section):

• Road Traffic Safety: Lowering the number of injuries (fatalities) on the highway/express roads…

•Traffic Engineering / Efficiency: Raise the overall performance of the transportation-systems…

• Quality and Comfort of Road Travel: Provide comfort & service applications for travelers…

Some of the essential advantages of a VANET model are briefly explained as in follows:

• Dynamic Topology: VANET environments have a frequently changing topology (unsteady) due to the high-mobility of the moving cars (vehicles).

• Frequent Disconnections: The link connection between the vehicles in VANET frequently disconnects because the nodes move, and the environment frequently changes.

• Mobility Modeling: An accurate mobility model is required for the efficient and realistic implementation of this highly dynamic VANET environment.

•Use of Other Technology: Nowadays, most VANET vehicles are capable of integrating their systems with other available technologies.

• No Power Constraint: VANET nodes have longer battery life than other MANET devices.

• Stringent Delay Constraints: VANETs are taking charge of delivering the CMEM "critical-medical-emergency-messages", which have to be delivered (transmitted) on a specific time to avoid loss & save human-lives [8].

3.1 RELATED WORKS / SURVEYS

In the realm of VANETs, too many reviews / surveys had been conducted, each shedding the light on different aspects of this technology. Below is a short overview of some notable works and how they differ from this paper,

1-"VANET Applications: Past, Present, and Future" by Michael Lee and Travis Atkison (2021): This paper reviews the evolution of applications over time in VANET field, highlighting past implementations, current trends, and future developments. While it provides a chronological perspective on applications, our paper emphasizes the structural framework, anticipated advancements, and the challenges that lie ahead for VANET.

2-"An Improved Deep Reinforcement Learning Routing Technique for Collision-Free VANET" by Pratima Upadhyay et al. (2023): This recent research paper describes a novel routing technique using deep reinforcement learning to enhance collision avoidance in VANETs. Although it presents new solutions to some technical challenges, our paper offers a more generalized discussion on the structure, future development, and broad challenges in the VANET area.

3-"Future Application Scenarios for MANET-Based Intelligent Transportation Systems" by C. Toh: The study explores potential applications of Vehicular ad hoc networks in intelligent transportation systems. It introduces an insight into the future applications, our paper focuses on the structural aspects and challenges specific to VANETs landscape.

In a brief summary, while existing literatures usually delves into specific technical sides or applications of VANETs, our paper distinguishes itself by providing a holistic discussion on the structure, anticipated future developments, and overarching challenges in the field.

The contributions of this paper are discussing a dataset specifically designed to reflect the unique characteristics of the Iraqi vehicular environment. This dataset should consider key factors such as (Urban Infrastructure) which includes (road types, traffic patterns, and vehicle behaviors) particular to Iraqi cities, (Mobility Patterns) includes (data reflecting driving behaviors influenced by local socio-economic and cultural factors), and (Environmental Conditions) such as (impact of weather, terrain, and infrastructure variability in different Iraqi regions).

This localized dataset is necessary for researchers that are focusing on VANETs in similar environments and can serve as a foundation for the development to more adaptive and context-aware routing protocols and communication models.

4. CHARACTERSTICS OF VANETs

For VANETs to be commercially viable, their design must consider many, and often conflicting, objectives. Figure 3 [9] shows the fundamentals of WAVE (Wireless-Access-for-Vehicular-Environment), a modern wireless access technique (incoming) developed for inter-vehicle and inter-roadside communications.

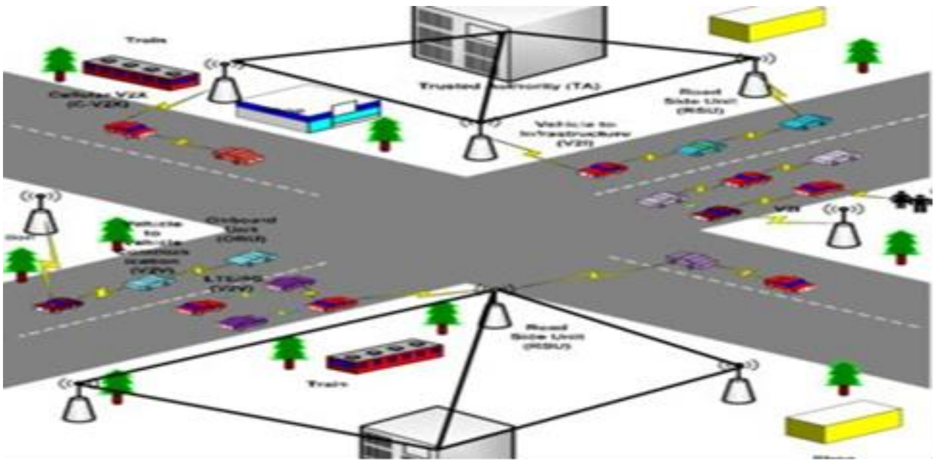

FIGURE 3 (WAVE) Architecture

While VANETs have certain similarities with MANETs [2][5][8], they also have unique characteristics that can be characterized as follows:

1-A rapidly changing network structure.

The dynamic architecture of VANETs is distinguished by the elevated velocity of the vehicles and the availability of several routes.

2-The network frequently has disconnections.

The cars' fast pace contributes to the dynamic topology, but it also causes frequent disconnections due to a lack of roadside units.

3-Modeling and forecasting Mobility

Forecasting the precise location and trajectory of vehicles is challenging. The features of mobility modeling and prediction in VANETs are dependent on the presence of pre-established roadmap models. Once again, efficient network design is dependent on vehicle velocity.

4-Communication Settings

Having a mobility model does not imply completeness. The mobility model's properties change depending on elements such as road infrastructure, highways, and urban contexts. Effective communication is critical in these situations and should be approached with prudence.

5-Strict time limits

Maintaining quick communication transmission is critical during an emergency. As a result, tackling such scenarios rather than focusing exclusively on high data rates is inadequate.

6-Use of inbuilt sensors

Sensors function as a means of communication. Sensors capture data on the vehicle's velocity and direction and communicate (connect) it to the data center. "Sensors" could be used for both (link creation and routing purposes).

7-Unlimited battery and storage capacity.

In contrast to sensor networks, nodes in VANETs are not limited by power or storage. As a result, duty cycle optimization is less critical in VANETs than in sensor networks.

5. STRUCTURE OF VANETs

Vehicles can contact (connect) with others (known as Vehicle-to-vehicle communication, or V2V), as well as with roadside equipment and infrastructure units on highways and roads, to form Vehicular Ad hoc Networks (VANETs), a type of "Mobile Ad hoc Networks" (MANETs) (also known as Vehicle-to-infrastructure communication, V2I). On-board units (OBUs) are units that are mounted on vehicles, whereas roadside units (RSUs) are devices that are present on the highways. The kinds involved in VANET structure for connection are as shown below in Figure 4 [10].

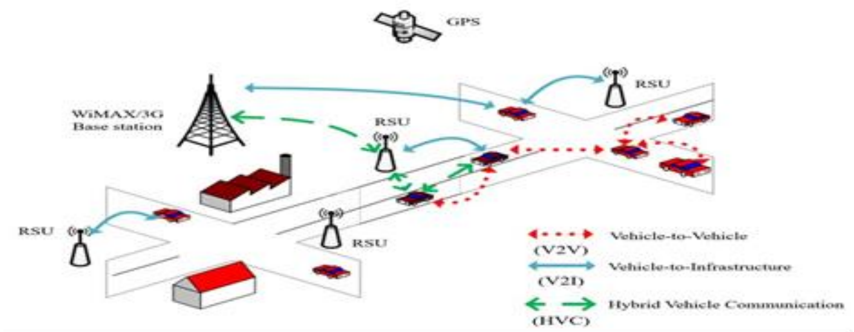

FIGURE 4 Main Framework of VANETs

In V2V communication, each on-board unit operates independently, sending messages via multiple intermediary devices. Still, in this configuration, the number and patterns of vehicles' movements significantly impact the formation of network connectivity. VANETs can build a predictable topology because, in most cases, cars are obligated to adhere to traffic restrictions by staying in their allotted lanes [11].

6. VANET APPLICATIONS

Figure 5 illustrates the primary applications of VANET [12].

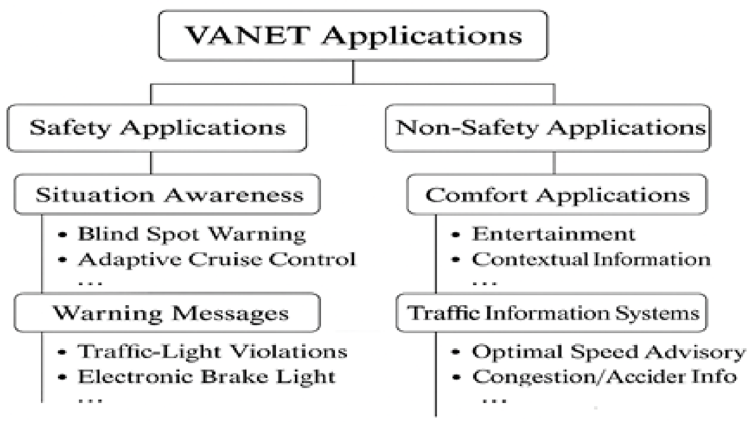

FIGURE 5 The VANET Applications

In upgrading transportation, VANETs are critical through different applications such as:

•Traffic Management: They enable real-time traffic information, allowing dynamic rerouting to reduce congestion and improve travel times.

•Safety Systems: VANETs improve road safety by utilizing collision avoidance systems, early warning alerts for accidents, and emergency vehicle notification.

•Infotainment: They provide in-vehicle internet connection, streaming services, and location-based marketing to enhance the passenger experience.

•Autonomous Vehicles: VANETs provide V2V and V2I communication, which is required for autonomous driving and coordinated vehicle movements.

•Environmental Monitoring: They help collecting data on air quality, weather, and road surface conditions, which contributes to innovative (smart) city projects.

These applications highlight VANETs' contribution for improving the safety of roads, traffic-efficiency, and intelligent transportation systems [13].

7. NETWORK MOBILITY MODELLING AND ARCHITECTURE

Vehicular ad-hoc networks do not own a predetermined architecture or topology to which they must adhere. A typical VANET comprises mobile vehicles that engage in communication with one other and with neighboring Roadside Units (RSUs). A VANET differs from a MANET; in a VANET, a vehicle does not travel randomly like nodes in a MANET. The vehicles in a VANET adhere to designated routes, including urban roadways and highways. While VANETs may be seen as a subset of MANETs, it is essential to acknowledge VANETs as a separate field of inquiry, especially concerning network architecture design. In the VANET architecture, a vehicle's on-board unit (OBU) comprises a wireless receiver and transmitter [14].

Generally, we can broadly categorize vehicles into three potential communication scenarios. One potential scenario is that all vehicles establish communication with one another via a Roadside Unit. This architecture bears resemblance to wireless local area networks (WLAN). In the second scenario, automobiles develop direct communication with each other, eliminating the requirement for any Roadside Unit. This can be categorized as an Ad-hoc architecture.

In the third scenario, certain vehicles can establish direct communication with each other, while others may require the assistance of an RSU to facilitate communication. This can be classified as a hybrid scenario [15].

Understanding network architecture is essential for adequately utilizing the potential of vehicle communication. The majority of researchers [15, 16] conducted their studies by categorizing VANET settings into three types: urban, rural, and freeway (highway). The main goal of this inquiry is to ensure that it addresses the need for inter-networking throughout the automotive environment.

Every environment presents unique obstacles that must be overcome. For instance, in a sparsely populated network such as highways, the primary concern is the low concentration of automobiles. Even in certain urban settings, a low penetration ratio and minimal night-time traffic can result in significant network latency [17].

The nodes' mobility is critical to mobile ad hoc wireless networks. Vehicles' intrinsic mobility makes communication scenario modeling extremely hard. Crucial components of vehicle mobility, including lane changes, acceleration, and braking, as well as human driving patterns, must be carefully considered in a VANET environment model [18].

The mobility model must include vehicle movement patterns both individually and collectively to provide error-free and efficient packet transmission in the VANET paradigm. In general, a mobility model is divided into micro and macro levels based on the level of detail required for modeling. Road, building, and street evaluations are classified as macroscopic, whereas vehicle behavior analysis is performed at the microscopic level [19].

Generally, the mobility models in VANETs may be classified into three categories [20]:

•Stochastic (Random Modeling)

•Traffic (Flow-based Modeling)

•Trace-based Modeling.

This encompasses a wide-range of topics, starting from the study of fluid dynamics to the analysis of stochastic processes, such as random walks and vehicle collective behavior. Alternatively, mobility modeling can also be determined by the level of unpredictability one desires to incorporate into the model.

Researchers have employed a variety of methodologies, including deterministic, hybrid, and random approaches (total), to predict dynamic behavior of moving vehicles in a network. Mobility-modeling significantly influences network performance analysis, affecting factors such as end-to-end delay, capacity, security, routing, and scalability. These are only a few examples of the impacts it can have. Ad-hoc networks can be more accurately modeled using suitable statistical and mathematical tools [13] [21].

One approach is to describe a wireless ad-hoc network as a random graph, with nodes represented by vertices and communication links represented by edges. A multi-hop wireless network's graph model is denoted as $G = (V, L)$, with V representing the set of vertices and L representing the set of edges in the graph. A graph of this type can be built using the Random Geometric Graph (RGG) approach, which distributes the vertices randomly and uniformly within a defined area using the Poisson distribution. This architecture resembles the interconnected graph of a Boolean architecture (BM) [22].

More studies are required to gain a more complete and analytical understanding of ad hoc wireless networks.

Signal transmission and reception present important obstacles in VANET research. The wireless channel over which the signal travels is highly variable and constantly changing. The signal is transmitted through a variety of scatterers, reflectors, and absorbers. As a result, precisely representing the signal is critical to ensuring accurate data extraction from broadcasts.

Typically, the signal at the receiver side does not take a direct path to its destination. Multiple signal paths are available for the transmission to reach the receiver. One challenge is combining the various aspects of the received signal to ensure correct data retrieval [23].

8. KEY RESEARCH AREAS OF VANETs

Despite the substantial research undertaken in VANET, other areas need more examination. Given VANET's unique properties compared to different communications in wireless networks and its demanding requirements for the design, there are various exciting research subjects in this domain. The paper summarizes a few of the leading research areas and challenges as below [24]:

(a) Service assurance (quality): Maintaining some VANET service quality standards is absolutely crucial. If a network lowers data delivery delay, maintains connectivity time high, and decreases the need for retransmissions, customers should expect a certain degree of Quality of Service (QoS). Ensuring this type of QoS for various user-applications and evolving network conditions in a challenging & exciting chore in VANET architecture.

(b) Developing an Effective Routing Algorithm: To ensure the prompt and precise transfer of data packets between nodes, an effective routing algorithm is essential. An effective routing approach in VANET decreases computing complexity, maximizes system capacity, and reduces delay. Current research on VANETs focuses on developing an algorithm capable of preserving the specified properties across various network topologies.

(c) Scalability and Robustness: Enhancing VANETs' resilience to accommodate increasing demands remains a continuous subject of research. Transitioning from low-density to high-density mode or from highly mobile to low-traffic conditions necessitates numerous design solutions that are insufficient for VANETs. We require a comprehensive VANET design capable of accommodating topological alterations and adapting to networks of diverse scales. Currently, research in the VANET environment is thriving.

(d) Cooperative Communication: Getting nodes to interact with each other presents a significant challenge for VANET. Many communication techniques from wireless network theory could not function effectively with VANET. Cooperative communication—that is, the ideal amount of data nodes should send to one another—is a fundamental topic of research in VANET architecture.

(e) Security of Network: Since nodes continually interact and share information, it is imperative to maintain certain sensitive data tied to the pertinent node when developing the VANET. The development of trust-based security protocols and effective authentication techniques is one interesting and active field of VANET study.

9. VANET GHALLENGES

Prior studies have demonstrated that VANETs encounter various obstacles that warrant attention. These challenges arise from the potential proliferation for the connected (communicating) devices (nodes) in the network system, resource utilization, imbalanced traffic flow, geographical conditions, uncertain network connectivity (unreliable), and broadcast storms [25-27]. Nonetheless, the goal of this paper is to address concerns about routing protocols as well as security & privacy issues in VANETs.

10. VANET ROUTING PROTOCOLS (Main Categories)

Routing is a procedure to transfer (transmitting) date packets from one network to another. VANET usually utilizes wire-less technology to connect apps and services [28] [20]. Furthermore, it has notable characteristics such as a high-dynamic topology and support for ir-regular connections. Nonetheless, the first VANET lacks the required routing algorithms, causing communication problems between networks. The existing VANETs have adopted a variety of protocols for routing, which can be divided into three categories: broadcast, geo-cast, and unicast [29-31].

• Broadcast (transmitting a message or a signal to a large audience simultaneously)

The use of this protocol is crucial in VANETs due to the necessity to distribute messages to unfamiliar destinations. Vehicular networks employ current message broadcast protocols, including a spatially aware packet routing algorithm, which anticipates and addresses persistent topological gaps through geographic forwarding.

• Geo-cast (multi-cast) routing

Geo-cast routing relies on a designated geographical location. The purpose of this establishment is to transmit packets from a source (car or device) to all other nodes that are within a specific geographical area. This method is known as (multicast routing). It establishes a particular location for forwarding packets, which helps to minimize message overhead and congestion in the network. Geo-cast is also considered a multicast service where the network is split according to the desired geographical region. Two examples of the protocols are the Distributed Robust Geo-cast protocol (DRG), and the Robust Vehicular Routing (ROVER).

• Unicast routing

VANETs use three types of unicast communication protocols: "Greedy, Opportunistic, and Trajectory-based". Greed causes nodes (vehicles) to send required packets to their farthest neighbors in the direction of the destination. The greedy traffic-aware routing protocol (GyTAR) [32] is one example of greedy routing. Nodes in opportunistic networks utilize the carry-toward technique to convey speculative packets/ data to the destination. In contrast, trajectory-based networks allow their nodes to calculate potential tracks (paths) to destination and transmit data through nodes beside with one or more of those lines. Table 1 below illustrates a sample of routing-protocols used in modern VANETs [33]. Routing protocols play a crucial role in maintaining scalability, but only a limited number of them have specifically addressed the need for routing protocols that facilitate data dissemination. The difficulty can be resolved by incorporating the "Internet of Things" (IoT) into the "Vehicular ad-hoc Network".

Table 1 Existing Routing-Protocols in VANETs

Routing / Approaches	**Routing / Protocols**
Unicast	AODV / GPRS / VADD / DSR / A-START
	Position-based Multi-hop-Broadcast (PMB)
	Improved-Greedy Traffic-Aware Routing (GyTAR)
	Trajectory-based Data-Forwarding (TBDF)
	CAR / GSR / OPERA / MaxProp / SiFT

Broadcast	DOLPHIN / BROADCOMM / DV-CAST
	Packet Routing Algorithm (PRA)

Geo-cast	DRG / ROVER

Figure 6 below displays the routing protocols and data diffusion in Vehicular Network (ad-hoc net) [34].

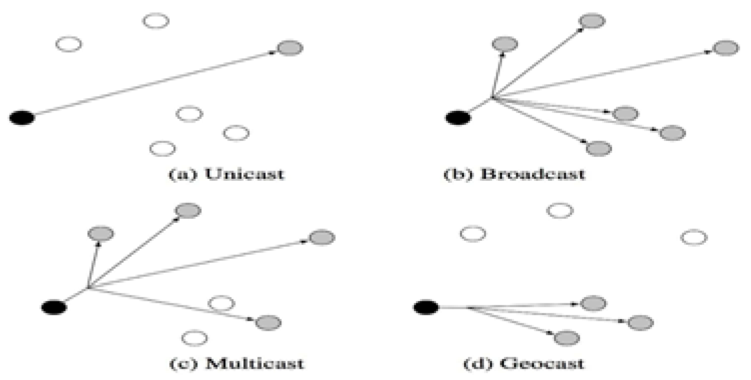

FIGURE 6 Routing Protocols & data diffusion in VANETs

11. SECURITY AND PRIVACY

The majority of academics in this scope believe that security & privacy are the most significant impediments to data or message transfer on VANETs. Due to the adoption of data integrity (online) mechanisms of the personal information, the kinematic data of VANET's components cannot be compromised by collaboration between hostile servers and users [35]. Recently, there has been an emphasis on resolving issues such as data ownership, large-scale data administration, and legal and responsibility concerns in this field. To address the issue, implementing a solid security architecture is critical for delivering both security and privacy. Therefore, the structural vehicular system for communication should firstly prioritize the establishment of a communication scheme designed explicitly for safety-related applications. This scheme will create an SSK "shared session-key" to ensure secure-communication inside the network. The presence of a low-security level in data clouds can potentially enable malicious individuals to generate fraudulent requests on the road or parking cloud services, resulting in possible mis-communication [36].

Existing VANET research has partially addressed various issues, including fundamental limits and opportunities, from a theoretical perspective. It has also considered the appropriate IEEE standards, type of connectivity between nodes and infrastructures, mobility, validation, and cross-layer design [37,38].

12. IOT APPLICATIONS AND VANETs

VANETs enabled by IoT have been extensively used in applications for both non-safety and safety-based to enclose efficiency and traffic safety by means of a broadcasting protocol. This concept originates from the concept of creating smart-cities where VANET systems are linked to IoT in related to maintaining information and data packages on the web and internet, sometimes named (the cloud).

The idea of smart cities is crucial to raising the quality of services (QoS) given to people and finally helping them to live in this modern age of technology.

Table 2 below contains some examples of the IoT's link with VANETs [39].

Table 2 An IoT Applications & VANET

IoT Application	VANET Application
Intersection-Collision-Warning (ICW)	Environment Monitoring
Lane-Change-Assistance (LCA)	Energy Management
Road-Map & Traffic Planning	Medical Healthcare System
Accident-Detection and Alerting (ADA)	Building Automation & Transportation
Overtaking-Vehicle-Warning (OVW)	Social network Smart Cities
Emergency Vehicle Warning (EVW)	
Point of Interest Allocation	
Weather Information Reports (WIR)	

13. ROUTING IN VANETs (TOPOLOGIES)

A significant obstacle in designing of VANETs is the creation of a dynamic routing-protocol capable of efficiently distributing information between static and moving vehicles. VANET routing differs from typical MANET routing due to the exceptionally dynamic and constantly changing topologies in the former. Several protocols initially created for the MANET environment have undergone testing in the VANET context [40]. Nevertheless, the issue persists regarding how to minimize the latency linked to transmitting the information between nodes. Addressing these problems in MANET protocols can make it easier to create real-time applications in the VANET environment.

Additional repercussions, such as reduced administrative requirements, must be carefully considered. To effectively deal with the unexpected dynamic nature of a vehicular's network design, the routing protocol must be adaptable to VANET's dynamic features. The most challenging part of routing in VANET is identifying and preserving the most effective communication paths within specific situations [41]. The majority of VANET routing protocols are inextricably linked to the network's topology, and performance variances occur whenever the network's structure changes.

Figure 7 [42] below explains that VANET routing may be categorized into six primary classifications:

- Ad-hoc or Topology-Driven Protocols
- Location-Based (Routing) Protocols
- Cluster-Based Protocols (CBP)
- Geo-cast Protocols
- Broad-cast Protocols
- Mobi-cast Protocols

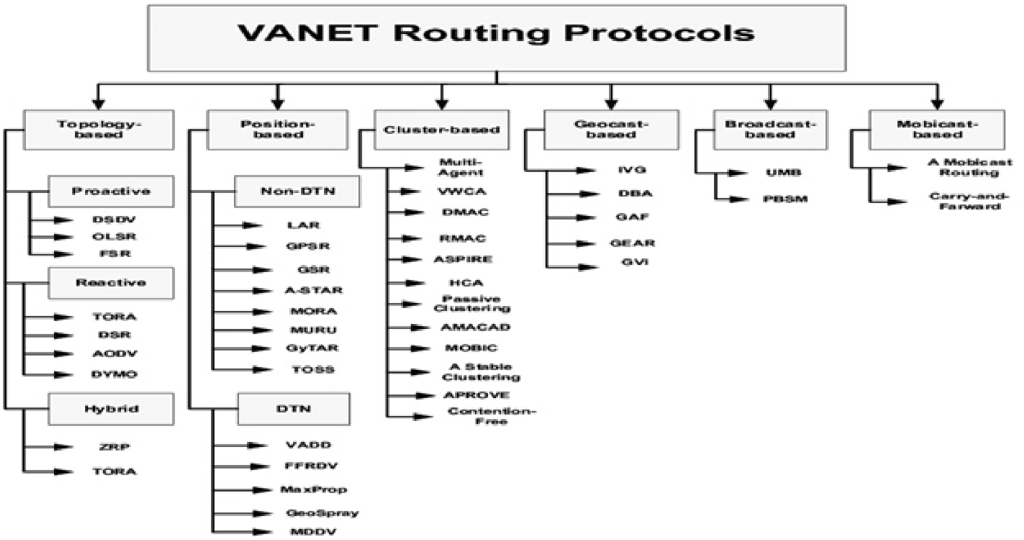

FIGURE 7 Routing Protocols in VANETs

14. COMPARISON OF WIRELESS TECHNOLOGIES IN VANETs

Several researchers had proposed, endorsed, and evaluated numerous high-speed wireless reach (access) methods and protocols for potential applications in VANET connectivity. New and current technologies and air interface protocols that can facilitate high-speed connections for vehicular contexts are now under consideration for VANETs. Some of those include [43]:

•Cellular Technology – (2G, 3G, 3.5G….. /4G/5G)

The 2G, 3G, and 3.5G technologies offer dependable security and extensive communication coverage, while the emerging 4G/5G technologies give significantly enhanced communication capacity and bandwidth. Various versions of cellular technology are already being utilized in fleet and telematics initiatives in the USA, Europe, and Japan. Nevertheless, the perceived excessive expense, along with its significant delay and restricted data transmission capacity, deters its potential application as a prospective communication infrastructure for VANETs.

• IEEE 802.11p-based Standards

The ASTM & an IEEE-adopted amendment is a modification to the IEEE 802.11 family that is specifically intended to support wireless communication in a vehicle. The IEEE Working Group is actively developing the air interface protocol. Its purpose is to enable communication between vehicles and between vehicles and roadside infrastructure. This communication will be possible at speeds between 200 km/h and 300 km/h, with an area range of up to 1000m. The MAC and PHY layers are both based on IEEE 802.11a standard. Vehicles manufacturing industry globally, particularly in the United States through VII and VSCC, Japan through the Advanced Safety Vehicle Project (ASV), Europe through C2C-CC, and Germany through SeVeCOM, heavily supports the deployment of IEEE 802.11p technology. Given the massive manufacturing numbers, the cost of adopting IEEE 802.11p is predicted to be relatively low when compared to cellular technology. As a result, this developing technology, also known as WAVE, outperforms cellular technologies and is better suited to VANET [44].

• Unified Wireless Access

ISO-TC 204 WG16, a group of the International Standards Organization, has made significant efforts to standardize several wireless access technologies. The process of unification resulted in a common communication system for vehicles known as the Continuous Air Interface for Long and Medium Range "CALM M5" [45]. CALM M5 included numerous interrelated air interface protocols and parameters, building on the current IEEE 802.11p foundation and including compatibility with previously mentioned cellular technologies. The merging of these standards into a unified standard will improve vehicle network performance by increasing the flexibility, capacity, the redundancy in packet receipt & transmission [46].

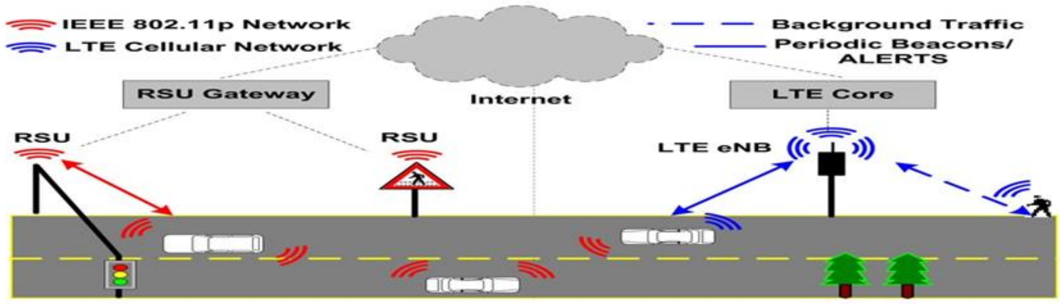

FIGURE 8 **Wireless Access Technologies [47]**

15. CONCLUSIONS AND FUTURE SUGGESTIONS

The continued success of VANETs is assured by the ubiquitous and ingrained nature of mobile devices in our everyday lives. Government initiatives have included it.

With its flexible platform, VANETs revolutionize ITS, enhancing traffic management, road safety, and driving experience. This paper delves into VANETs' inner workings, focusing on their structure and the characteristics (attributes) that differentiate these features from different more ad-hoc networks, including their high-mobility, dynamic topology, and capacity to connect withs vehicles (V2X).

While VANET technology has come a long way, there are still some issues. Lack of scalable network architectures, inadequate security protocols, and poor spectrum utilization are obstacles that must be overcome for VANETs to realize their full potential. Attempts to offer low-latency data transfer and dependable communication face further obstacles because of the complicated urban settings in which these networks function.

In addition, VANET protocols are fragmenting due to different countries' approaches to standardization, which may hinder their wider acceptance. To sum up, VANETs are promising, but these infrastructure and technical issues will prevent their successful integration into future smart cities. A few of critical areas set the trajectory of VANETs' future development:

1. Enhanced Safety Measures: Future research efforts should center on creating adaptable security algorithms that are lightweight and capable of fighting cyber threats in real-time while minimizing processing load. Intrusion detection systems that use blockchain technology and artificial intelligence (AI) would be a good option.

2. VANET latency might be drastically reduced with help of 5G networks and edge computing, enabling cars to operate data closer to their source. Future research focuses on how effectively these technologies scale for large-scale implementation in densely populated areas.

3. Machine learning and artificial intelligence can enhance network efficiency by predicting future traffic patterns and facilitating more effective routing algorithms. The integration of AI with VANET infrastructure could improve adaptive communication protocols and real-time decision-making.

4. The efficient running of worldwide operations depends on the standardization and its implementation of VANET's communication protocols worldwide. Businesses, governments, and universities should work together to encourage future cross-cutting standardization.

5. Prioritizing Energy Efficiency in Design: Efficient communication and hardware should be part of future VANET advancements in light of the increasing focus on sustainability. Renewable energy source integration into roadside unit power systems and the development of energy-efficient routing algorithms are among these responsibilities.

Lastly, the development of VANETs depends on the collaboration of experts from various fields, including transportation, computer science, urban planning, and telecommunications. Such synergies can drive innovative solutions that meet the complex needs of intelligent transportation networks (ITN).

Studying VANETs and IoT applications is very crucial for enabling ITS with enhanced security, safety, efficiency, and real-time exchange of data. Emphasizing privacy, and adaptability will shape future advancements, ensuring resilient, scalable, and trustworthy vehicular communication networks.

VANETs have made great strides toward creating safer and smarter transportation networks, but they are far from finished. The aforementioned suggestions are a blueprint for continuing R&D efforts to establish VANETs as an integral part of future intelligent transportation networks.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest

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