Wasit Journal for Pure Science

Journal Homepage: https://wjps.uowasit.edu.iq/index.php/wjps/index
e-ISSN: 2790-5241 p-ISSN: 2790-5233

A Comprehensive Review for different perspectives in Ad-Hoc/ Cellular VANET Networks: Taxonomy, Challenges, Routing, Future Directions

Jaafar Sadiq Alrubaye [1]*, Mohamed H Ghaleb Abdkhaleq[2], Ahmed Fadhil Qataif [3]

[1]College of Education for Pure Sciences, Faculty of Computer Science, University of Wasit, IRAQ.

[2]Faculty of Computer science and information technology, University of Wasit, IRAQ

[3]College of Education for Humanities, University of Wasit, IRAQ

*Corresponding Author: Jaafar Sadiq Alrubaye

DOI: https://doi.org/10.31185/wjps.594
Received 20 October 2024; Accepted 10 December 2024; Available online 30 December 2024

ABSTRACT: Vehicular Ad Hoc Networks (VANETs) have emerged as a critical area of research due to their dynamic nature and potential to revolutionize road safety and traffic management. As a subset of Mobile Ad Hoc Networks (MANETs), VANETs enable seamless wireless communication between vehicles and infrastructure, providing real-time updates and predictive insights into road conditions. This study delves into the core components of VANETs, including their architecture, functional elements, and communication protocols, while addressing key challenges such as efficient routing, network reliability, and scalability. Performance metrics like Packet Delivery Ratio (PDR) and packet loss are thoroughly analyzed to evaluate the system's robustness. Furthermore, the research contrasts various routing strategies—such as topology-based, geographic, and cluster-based approaches—highlighting their strengths and limitations compared to traditional cellular network methodologies. By offering a comprehensive evaluation of VANET routing protocols and their impact on communication efficiency, this study contributes valuable insights to the development of secure and reliable vehicular communication systems.

Keywords: MANET, VANET, V2V communication, Routing, 4G, 5G, C-V2X

1. INTRODUCTION

The advancement of VANET technology began in the early 1990s and has seen significant progress in the past few years [1]. The need for principles in this area is highlighted following significant advancements in electronic road tolling systems utilizing various specialized active Radio Frequency Identification (RFID) transponder systems. This basic concept was expanded to accommodate various vehicular communication applications. Numerous research projects have been carried out during this period to improve road safety and comfort features by advancing the Intelligent Transportation System (ITS). The cardiovascular information system, part of the European Commission's Program, identified, established and assessed appropriate technologies for enabling vehicles to communicate with each other and nearby roadside units. A proposal for an Integrated Scheme called "e-safety SAFESPOT" in Europe aimed to create interactive supportive vehicle networks that can collaborate and exchange information with the roadside units. Supporting drivers with instant information about their surroundings, including road users and other vehicles, can improve Intelligent Transportation Systems (ITS) [1, 2]. Additional improvements and other advanced technologies will help enhance road safety, passenger comfort, and driving conditions [1]. Currently, the world is adjusting to the idea of the Internet of

*Corresponding author: jsadiq@uowasit.edu.iq

Things, altering the way we perceive everything in our surroundings, including urban areas. Truly, intelligent cities are a fascinating new use of the Internet of Things, integrating existing infrastructures with innovative technologies to enhance transportation, energy usage, and environmental sustainability. In this situation, VANET serves a crucial function by enabling intelligent communication among vehicles, ultimately enhancing traffic flow and safety on the roads [3].

The vehicle should have onboard side units like GPS systems, as well as roadside units on infrastructure elements along the streets. Communication between vehicles can occur directly through V2V communication, or when the signal is weak, road infrastructures can serve as a link between vehicles for V2I communication over longer distances.

The necessary distinct services depend on sharing data in vehicular networks. Efficient distribution of data between vehicles, done in a timely manner, is crucial and has a significant impact on communication effectiveness. The data is being actively spread through a technique called proactive data diffusion. Most safety-related data in VANETs is typically sent using a broadcast method [4]. In today's time, numerous researchers are drawn to VANETs because of their attractive features like dynamic topology, lack of centralized organization, dynamic connectivity, and self-organization [5].

Most of the recently produced vehicles comprise the possibility of utilizing an “Intra-Vehicular Network" in which the communication among vehicles and/or the fixed infrastructures is conceivable. Different wireless communication tools (gadgets) can be utilized in this fashion, such as Global Positioning System (GPS), On-board units, Smartphone, Media Players, Bluetooth, etc. Modern vehicles rely on on-board units, sensors, GPS, and other communication capabilities as integrated components. The ongoing process of implementing and maximizing the use of these techniques involves developing, producing, and utilizing approaches. Because of these factors and additional reasons, VANETs are becoming a reality with the growth and development of their technologies [7]. The progress of technology and its use have made VANETs the suitable tool for enhancing various transportation services. Routing is the primary focus of research in VANET. Finding the right type of transmission and different topologies, as well as maintaining stable and consistent routing performances, is the most difficult task. The shining routing protocols in VANET need a comparative study to keep pace with the fast development of wireless technologies like different cellular releases. Figure 1 shows a basic illustration of the hierarchy in Wireless ad-hoc networks [12].

1.1 Motivation

While VANET research has made notable strides, significant gaps remain in understanding and optimizing routing strategies for dynamic vehicular environments. Many existing studies focus on specific routing protocols without providing a holistic comparison of their performance across different metrics. Moreover, the integration of VANETs with modern cellular technologies and their unique challenges is underexplored. This manuscript aims to address these gaps by analyzing and comparing diverse routing protocols, examining their performance in terms of Packet Delivery Ratio (PDR), packet loss, and overall reliability. The study highlights the distinctions between routing approaches in VANETs and traditional cellular networks, contributing to the development of secure, efficient, and adaptive vehicular communication systems.

The paper is organized as follows, Section 2 presents different perspectives for MANET and VANET. Section 3 explained the architecture of VANET, Section 4 discusses the attributes of VANET, the VANET challenges are resented in section 5, the application of VANET are also represented in section 6, and the VANET routings are discussed in details in section 7, section 8 give sufficient information about the routing in cellular compare to ad-hoc routing discussed in previous section (section 7), lastly, the paper present key performance metrics, and discussion along with future directions in section 9 and 10, respectively.

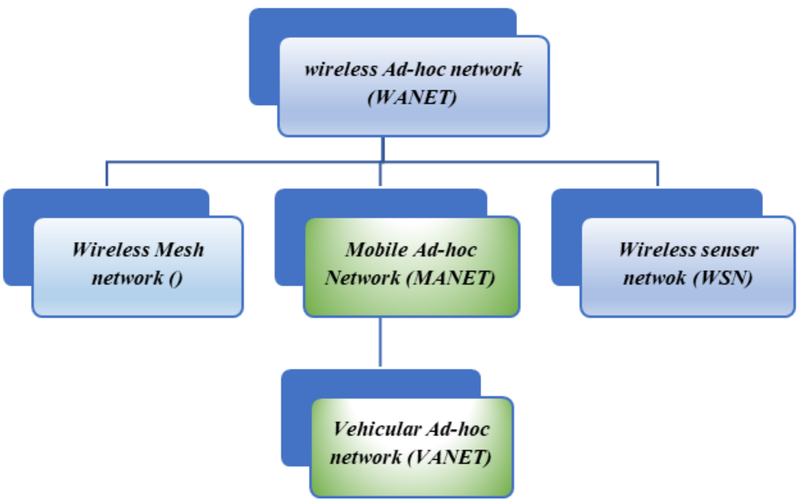

Figure 1. Classification of Wireless Ad Hoc Networks (WANETs) [15]

2. MANET& VANET ANALOGY

MANETs function in a distributed manner without the need for infrastructure. These networks are used in a range of military and civilian settings including surveillance in battlefields, monitoring borders, robot networks, disaster response, and vehicle networks. Nodes in MANET are mobile, moving without restrictions or constraints. MANET has been created to form VANET, which sets up the crucial progress stages in smart transportation applications. The nodes in these networks are sharing and spreading data wirelessly. Numerous obstacles are impacting the dependable transmission of these networks. To decrease the flooding produced due to the unsuccessful dissemination, numerous routing procedures are proposed. routing is a method to calculate routes among certain nodes based on some criteria like density, short path, link weight, etc. routing tries to avoid network problems like, local optimum, short link lifetime, real time application delay, and packet drop and loss, etc. Each routing protocol has its own specific principles that greatly influence its overall stability [8].

3. VANET ARCHITECTURES

The advanced progress in communication technology enables different uses for vehicle networks in urban, rural, and highway settings to maintain various levels of service quality in numerous applications. The primary goal of a VANET is to establish reliable wireless connections between vehicles and/or RSUs [9][10]. Thanks to advancements in wireless communication, intelligent vehicle technology, and automotive manufacturing, modern vehicles now come equipped with specialized wireless communication units. These devices facilitate communication between vehicles and nearby vehicles using a V2V approach, as well as with RSUs using either a V2I or I2V approach [13]. Enabled by IEEE 802.11p technology, Dedicated Short-Range Communication (DSRC) allows OBUs to share information via vehicular networks using V2V and/or V2I [11][12]. The main important vehicular communications are represented by the following three types:

- ***Vehicle to Vehicle*** Communication V2V communication is a beneficial technology suggested to improve communication between vehicles to boost road safety (shown in Figure 2). It offers a great chance to gather comprehensive information on the current condition of road traffic. Vehicles are being prompted to transmit alerts regarding accidents and hazards ahead of them to all following vehicles on the same road [13]. Vehicles can communicate directly with nearby vehicles via V2V without the need for fixed communication units on the road. An OBU-equipped vehicle can communicate wirelessly and exchange information with nearby vehicles. This technology intends to establish a specific communication and collaboration connection between vehicles within radio range [14][15].

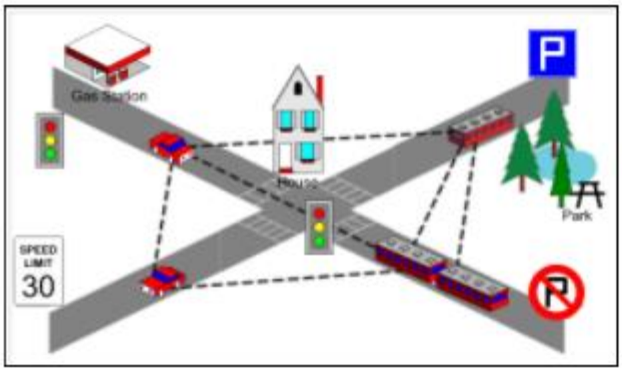

Figure 2. **Illustration of Vehicle-to-Vehicle (V2V) Communication in a Smart Traffic Environment [16]**

- ***Vehicle to Infrastructure*** Communication the V2I communication mode allows a vehicle to only share information with the RSUs. RSU has the capability to offer both safety and non-safety applications to vehicles' OBU as well as other roadside units [15]. Vehicles can communicate with fixed infrastructures (roadside units or cellular) using V2I or I2V interactions. In these methods (shown in **Error! Reference source not found.**), the stationary instruments by the roadside are crucial for gathering key road and traffic data to suggest specific actions for local vehicles. RSU has the capability to communicate and engage with the vehicle's on-board unit (OBU) [16].

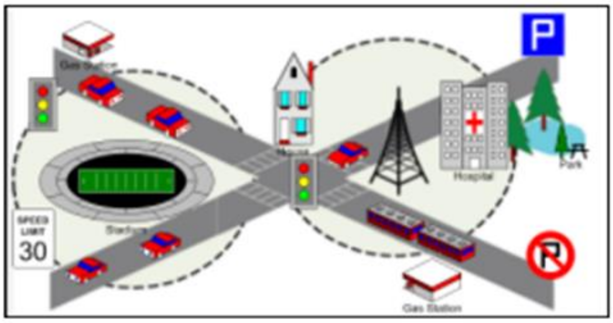

Figure 3. Illustration of Vehicle-to-Infrastructure (V2I) Communication in a Smart City Environment [16]

- ***Hybrid architecture*** (Mixed V2V-V2I approach) In a hybrid communication approach (shown in Figure 4), a vehicle can chat with nearby vehicles using V2V and with fixed external devices using V2I (or I2V) through single or multiple hops [17]. This method combines V2V and V2I. FCC, also known as the "Federal Communications Commission", implemented a unique wireless protocol called DSRC. DSRC was created for ITS to operate within the 5.9 GHz frequency range with a total bandwidth of 75 MHz [18]. One control channel (CCH) and six service channels (SCHs) have been allocated within the frequency band in use. The CCH is utilized to distribute safety applications and security messages, while the SCHs are used for disseminating various types of service data [5].

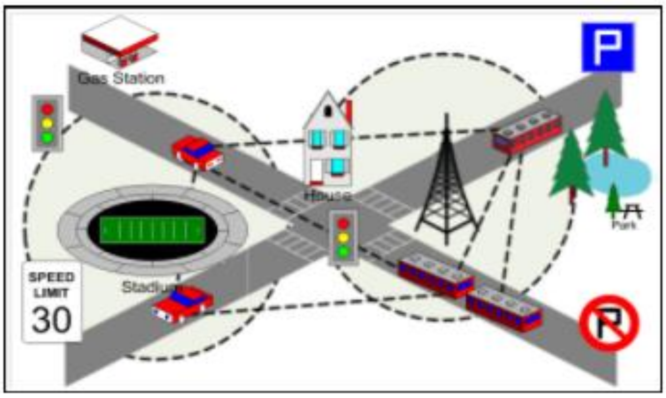

Figure 4. Hybrid Vehicular Communication in a Smart Traffic System [16]

4. ATTRIBUTES OF VANET

VANET can be distinguished from regular MANET by its unique characteristics. Below are the key features of VANET that are considered the most significant [19][20][21], also shown in Figure 5:

- **Movement**: Vehicles can travel on roads at a specific speed limited by factors such as intersections, traffic lights, and weather conditions like rain, snow, and storms. Certain rules can be used to forecast their future movements.
- **Power source:** The power required for VANETs communication devices is negligible and has no restrictions. Vehicles come equipped with their own durable battery for power.
- **Extensive network:** A high volume of vehicles on streets creates a widespread network, especially in crowded areas like city entrances, city centers, checkpoints, and highways.
- **Network density** in VANETs fluctuates due to the varying traffic flow of vehicles. In rural areas, the network density is minimal but can become dense during rush hours or traffic jams [3]. High mobility of vehicles on highways results in a heightened likelihood of network partitions occurring. Because of this, it is not guaranteed that end-to-end communication will occur [22]. Irregular connectivity can lead to packet loss issues, affecting traffic safety. Therefore, it is essential for a node to maintain a global network topology. Please rephrase the text you provided for me to paraphrase. A hierarchical network topology, known as a cluster, has been recommended for VANETs to deal with and overcome their unique features [23].

- **Localization methods**: In some situations, like transitioning from driver safety to assistance and internet connectivity, VANET is considered a useful solution for categorizing applications into safety, non-safety, and infotainment. Localization is crucial as it offers data on the vehicle's speed, position, and direction while traveling within the network. The real-time whereabouts of vehicles in vehicular communication is essential [24].

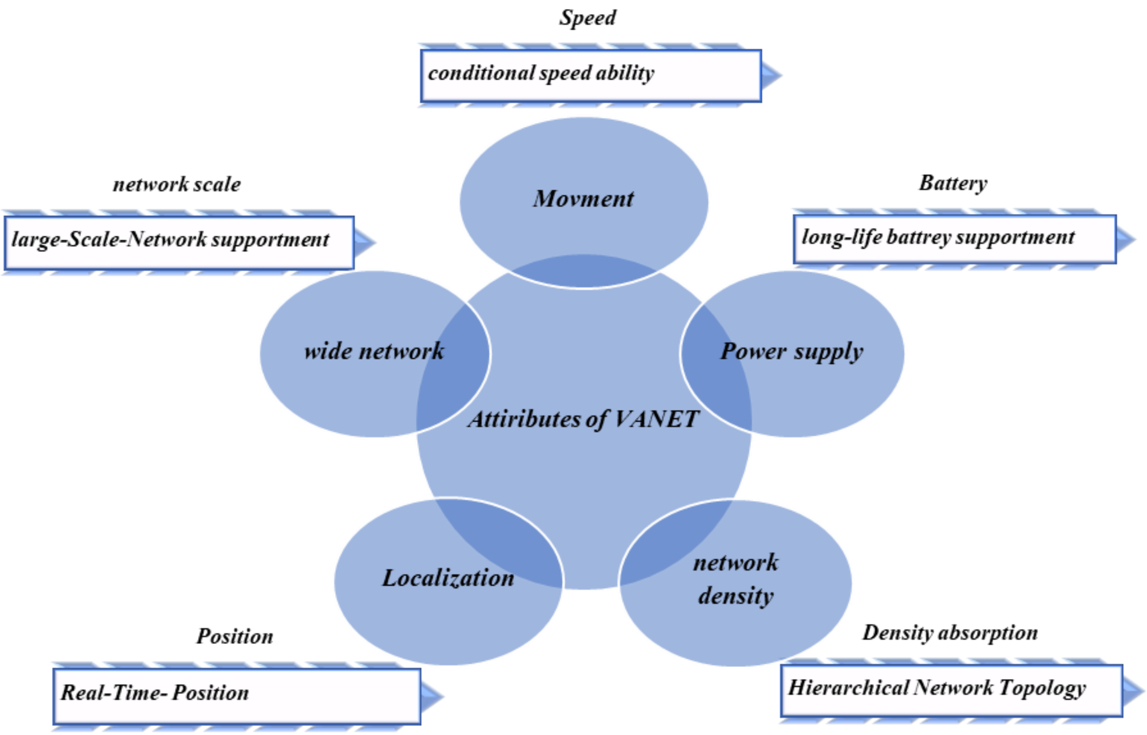

Figure 5. Attributes of Vehicular Ad Hoc Networks (VANETs) [Author]

5. VANET CHALLENGES

Various applications are used in ITS range from traffic safety applications to passenger infotainment. Such diversity of applications creates different requirements on vehicular communication procedures also shown in Figure 6. These requirements add the following new challenges [3][25][26]:

- **Bandwidth limitations:** VANETs lack a centralized controller to manage limited bandwidth and content functionality. Channel congestion is a difficult issue that VANETs in densely populated areas must face.
- **Delay constraints:** Time constraints must be met in VANET communication protocols to ensure efficient operation. Time strategies in VANETs must be strictly adhered to.
- **Privacy and accountability rights**: Balancing privacy and accountability rights is essential in vehicular communication. Every vehicle must trust the source of the information it receives while also safeguarding the privacy of the driver.
- **Cross-layering protocols:** Protocols that span across different layers: real-time applications like multimedia are greatly limited by time and location variables. Therefore, establishing a reliable connection at the transport layer is crucial in this scenario because of the ever-changing topology and frequent route changes. Hence, developing appropriate cross-layer protocols is crucial for implementing VANETs.
- **Limited communication distance:** VANETs typically have a short communication range, resulting in poor connectivity among vehicles. Therefore, it is impractical for every vehicle to maintain the entire topology of VANET, leading to potential challenges for its routing protocols.
- **Security threats:** Since VANETs are networks in open environments, they are susceptible to a large volume of attacks. One of the primary security obstacles involves identifying various attacks on vehicular communication and ensuring the safety of routing protocols from these attacks.
- **Topology changing**: Vehicles' high mobility in dynamic environments results in frequent changes to the network topology of VANETs. In conclusion, VANETs face numerous difficulties during their implementation, such as unpredictable connectivity, frequent link disruptions and disconnections, and the frequent changes in network topology. Because of these factors and additional ones, a new research framework known as "Vehicular Delay Tolerant Networks (VDTNs)" has been introduced to address these circumstances.

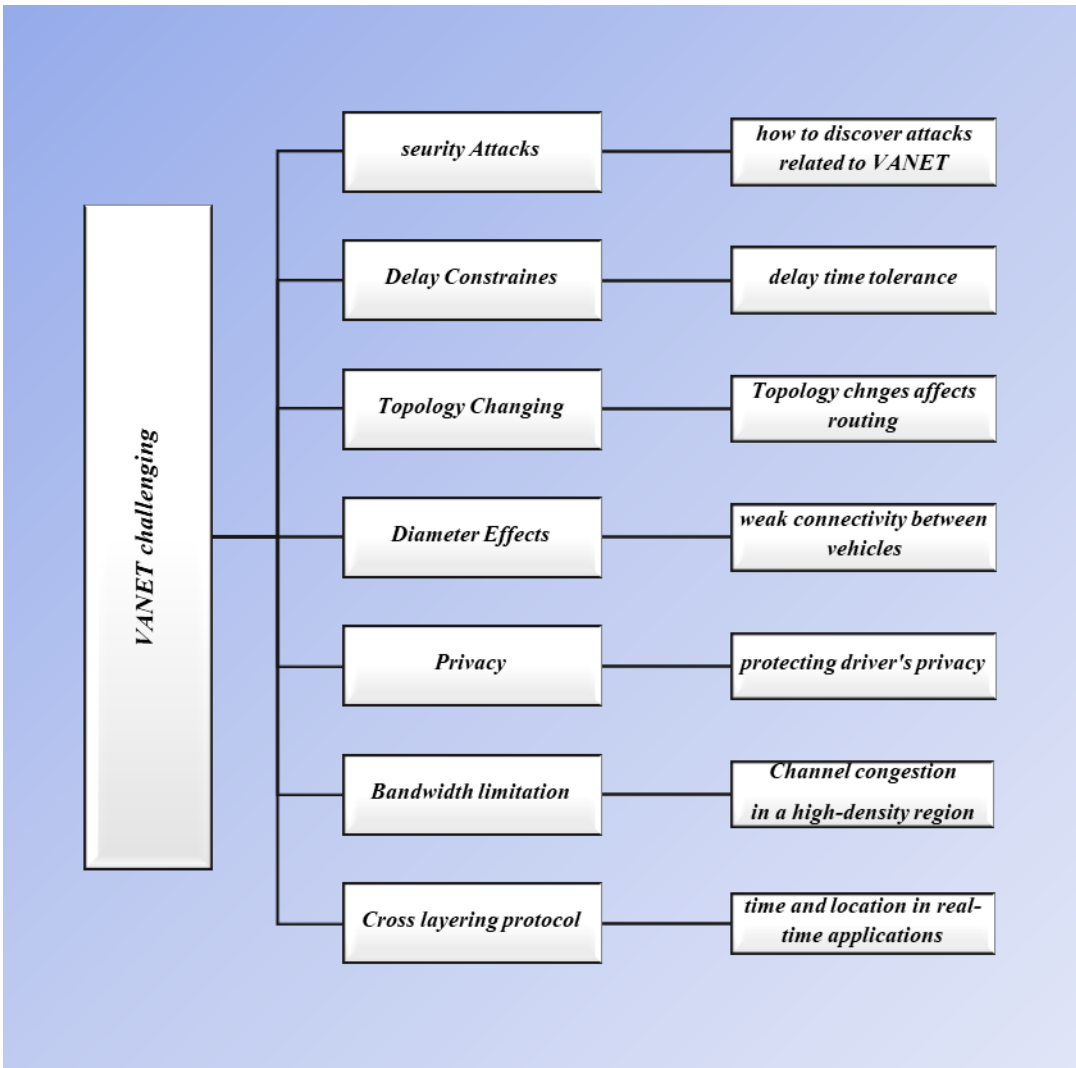

Figure 6. Challenges in Vehicular Ad Hoc Networks (VANETs) [Author]

6. APPLICATIONS OF VANET

The applications of VANETs involve enabling vehicles to communicate with one another along a designated route [27]. It facilitates communication among vehicles in motion. The main critical uses of VANETs are intelligent traffic management, Lane merging aid, and emergency vehicle notifications [28]. Other potential applications include traffic management, assistance with lane changes/merges, and warning systems for emergencies and collisions. VANETs aim to greatly decrease both traffic congestion and road collisions [28]. If there is heavy traffic or a traffic accident up ahead, a vehicle needs to quickly send a warning message to the vehicles behind it. These distant vehicles could potentially discover a different path to bypass the congested area [29]. According to the function of application, Figure summarizes different categories of applications in VANET. Where Applications, that we must referred to are application of road efficiency, application of road safety, and applications of commercial & information.

- However, applications of **Road Efficiency (RE)** are subcategories according to the improving of road conditions, managing and monitoring of vehicle traffic into, Traffic monitoring and Traffic managing. The first monitors the vehicle's roads and conditions of VANETs area and based on irregular of driver's notification and authorities of traffics is divided into, Monitor of Road Conditions, and Vehicle Tracking and Tracking Agent. The second is divided based on traffic flow and condition. The traffic managing application falls into four subcategories, route guidance and improved navigation, speed control, traffic-free tolls, and Intelligent traffic control.
- The application of **road safety (RS)** tries to reduce human injuries and vehicle damage caused by traffics accident. However, improving the safety of the road is required, so the application related to improving the traffic can be subcategories into Incident management, Traffic sign notification (RSN), and Collision avoidance. However, Incident management is responsible for emergency events for traffic accidents, these events are either Emergency Vehicle Alarm or Shock Warning /Post-Collision. Traffic sign notification (TSN) is the other application of road

safety, which is responsible for warning vehicle drivers, and the assistance of the road signs. Where collision avoids subcategories like (dangerous location alarm, line change warning, pre-collision warning, and warning of intersection collisions) are assisting to detect risk of collision among every two vehicles by generating proper warnings.

- Applications **of commercial and information** is defined as the information and entertainment services given to drivers, and these are divided into Background information, and Entertainment. Background information is just a location of interesting information like restaurant or hotel, or position-based information. Some of this information are, Information on favorite hotel or restaurant, or information of Location and Parking Reservation, and information of Updates and Download Maps.

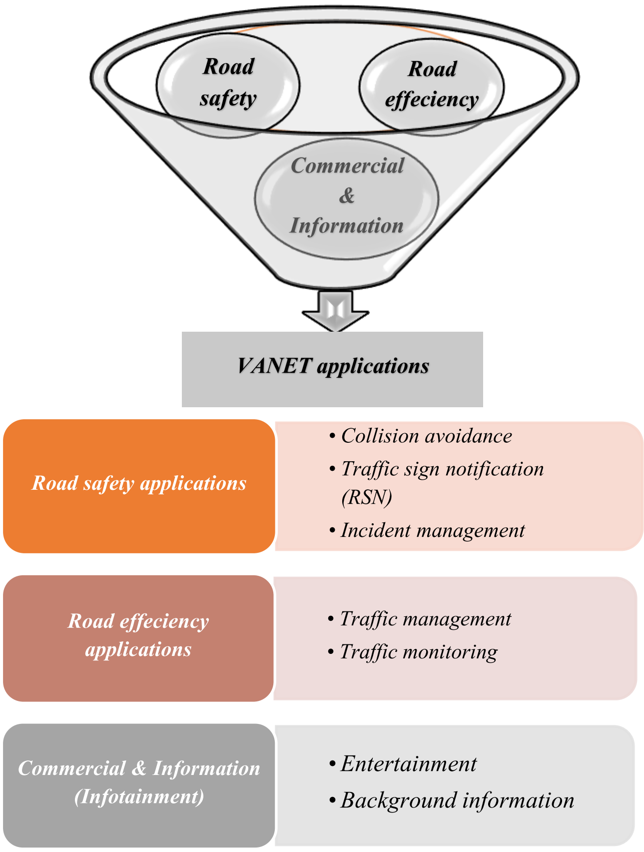

Figure 7. Categories of Vehicular Ad Hoc Networks (VANETs)

7. VANET ROUTING

Routing is the primary focus of research in VANET. The most difficult task is locating the suitable designated transmission type and the consistently changing topologies, with routing performances that remain stable and reliable. The routing protocols in VANETs need to dynamically create and sustain routes during communication by considering various performance metrics such as end-to-end delay, throughput, Packet Loss Ratio (PLR), Packet Delivery Ratio (PDR), and Overhead transmission (OH). If they lose the path, they must quickly find alternate routes without delay. The effectiveness of routing protocols in VANETs is greatly influenced by both internal and external factors. Different of VANET routing protocols based on different categories shown in Figure 8 are classified, these categories are the below [22] [33]:

7.1 Topology based routing

7.2 Position based routing

7.3 Cluster based routing

7.4 Geo-based routing

7.5 Broadcast routing

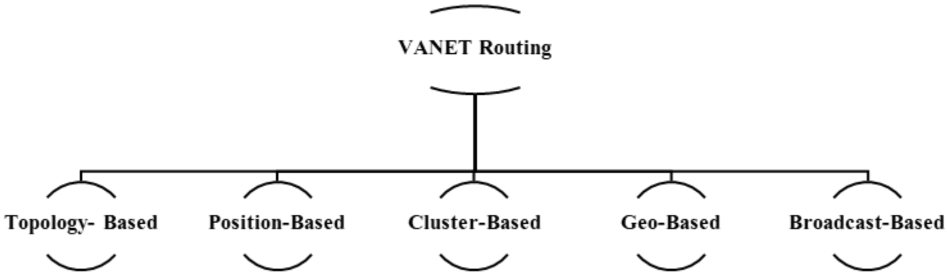

Figure 8. Various routing protocols of VANETs

7.1 Topology-Based Routing

Generally speaking, VANETs are networks without infrastructure, and various routing protocols developed for previous ad-hoc networks like MANET can be used in VANETs with some adjustments. Topology-based protocols are categorized into three types: proactive, reactive, and hybrid. Several protocols were created to meet the requirements of the VANET setting [14],[30],[16],[23],[27]. Topology-centric routing protocols must establish and uphold a comprehensive route stretching from the starting node to the end node [31], which plays a crucial role in Packet Delivery Ratio, Throughput, and End-to-End delay [8]. Topology Based Routing schemes typically need extra node topology details when making routing decisions. Topology-based routing protocols are categorized into Proactive, Reactive, or hybrid types as shown in figure 9.

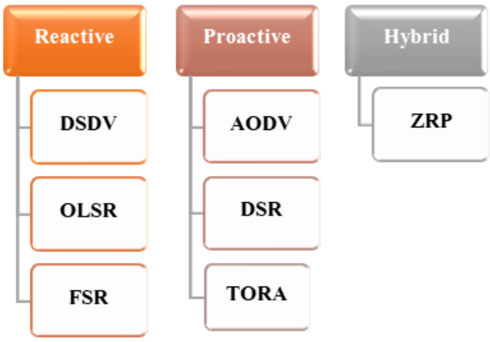

Figure 9. Topology-based routing Protocols of VANETs

7.1.1 Proactive routing protocols

Proactive routing involves keeping routing information, such as the next forwarding hop, updated in the background regardless of communication demands. The packets are consistently sent out and spread throughout nodes to sustain the path, followed by the creation of a table within each node that shows the next node to hop towards the destination. Proactive routing protocols have the benefit of not needing route discovery as the destination route is already saved, yet they have the drawback of offering low latency for real-time applications and maintaining unused data paths which reduces available bandwidth. The different categories of proactive routing protocols include:

7.1.1.1 DSDV (short for Destination Sequenced Distance Vector)

DSDV is a routing scheme that relies on tables and is employed in ad-hoc mobile networks. The basis of it lies in the classical Bellman-Ford routing algorithm, which is utilized to choose the shortest route between in-neighbors and out-neighbors. Every packet contains an incrementing sequence number to avoid looping, address the infinity-count issue, and speed up convergence. It regularly swaps these tables with nearby nodes. Two approaches will be employed for updating routing tables. Firstly, the method of "full dump" involves sending the entire routing table in an update message. The next approach is the "incremental update" method, which includes only the data for the entries that have had slight changes since the previous full data transfer. When the nodes identify a broken link [19], they assign a value of infinity to all routes passing through it. It then advises nearby residents of another shorter route to a specific location. This feature enables DSDV to have a highly efficient route establishment process. In contrast, this process in extremely active networks like VANET generates a significant amount of management data, causing a high usage of network capacity [34, 35].

7.1.1.2 OLSR

The Optimized Link State Routing (OLSR) is a proactive routing protocol ideal for ad hoc networks like VANET, however, its major drawback is the requirement to constantly update the routing table with all potential routes. The studies by Khan and Qayyum (2009) and Wei and Li (2008) demonstrated that typical MANET routing protocols are not suitable for VANET deployments in urban or highway settings due to increased routing load, decreased packet delivery ratio, and longer end-to-end delays. In contrast, OLSR remains the most effective protocol for VANET applications [36].

7.1.1.3 FSR

FSR is predicated on the idea that modifications in the distant topology will not significantly impact the computation of the local routes. The purpose of the distance function is to refresh the routing table changes within the network. In FSR, all nodes refresh and share their neighboring nodes' routing details instead of burdening the whole network with updates. All nodes relay information one step at a time as it is being transmitted. FSR captures the complete network structure but cannot guarantee the correctness of all connections between faraway nodes [37].

The advantages of proactive routing protocol are:

- It has very low latency for real-time applications.
- Route discovery is not required.
- Exchange partial routing update information with neighbors only, so consume lesser bandwidth.

The disadvantages of the proactive routing protocol are:

- No response on link failure.
- A significant portion of the available bandwidth is taken up by maintaining routing paths that are not being used.
- The increasing of the network size increases the routing table processing overhead and storage complexity.

7.1.2 Protocols for routing that are responsive to changes (Reactive routing protocols)

Reactive routing protocols, also known as on-demand routing, establish the routing path based on demand and only maintain the currently used routing paths, reducing network overhead. Reactive routing is particularly suitable when vehicle data transfer is limited to a small number of routes. Several reactive routing protocols have been created, such as Dynamic Supply Routing (DSR) [38], Temporally Ordered Routing Protocol (TORA) [39], and Ad hoc On-demand Distance Vector Routing (AODV) [39].

7.1.2.1 Dynamic supply Routing (DSR)

It functions as a source routing protocol. The use of (Hello) packets is avoided in order to decrease the bandwidth used by Control packets [25]. While constructing routes, each node stores all routes initiated from itself to another node [40, 41]. When a node needs to send a message, it will first check the route cache to see if there is a valid route to the desired destination. Once located, the transfer process begins. If not, a different method of finding a route is created by broadcasting route request packets throughout the network. These packets include the address of the starting node, the ID of the ending node, and a unique sequence number to avoid looping information. Each node that receives the packet verifies its sequence number before transmitting it to neighboring nodes, including its own address information if it is not meant for that node. If the node detects a broken link, it will generate an error message and send it to the source. After removing broken links, the source may initiate another route request if necessary. Using DSR [38], the network is fully self-configured and self-organized, eliminating the need for administration or existing infrastructure. Sender nodes are already aware of the entire hop-by-hop route to the destination node, as these routes are stored in the route cache [39].

The advantages of DSR are

- No periodic update is needed in DSR.
- It employs caching for future route discovery, which helps lessen the burden on the network. Where there is little strain on the network to find a path between nodes.
- Beacons are fewer.

The disadvantages of DSR are

- The system is being overloaded due to avoidable flooding.
- At the high mobility model, it performs worse.
- Locally, it is unable to repair broken links.
- In high density nodes network, overhead byte caused by the route information inside the header.

7.1.2.2 Ad hoc On-demand Distance Vector Routing (AODV)

This on-demand routing protocol in wireless networks stores routing data in routing tables. Each mobile node will be assigned a timer as part of this protocol. Upon termination of the route, this routing table will remove those entries temporarily. Routing data is stored in the routing table of an on-demand routing protocol. It operates in two steps: The initial step is crucial for locating and preserving a path. The discovery phase of route communication is performed by the intermediate node and the source node. When a node connection failure is detected, a route-error message is sent out to address the issue. Information spreads until it reaches its final destination [39] [8].

The advantages of AODV are

- A contemporaneous arrival at the destination is expected because of the numerous destination routes being utilized.
- It lowers the demand for memory and eliminates unnecessary routes.
- AODV reacts to link failures in the network.
- It is suitable for ad-hoc network applications on a large scale.

The disadvantages of AODV are

- Setting up a connection for communication to establish a route takes longer compared to other methods.
- The path could lead to uniformity in the case that middle nodes have outdated information.
- Having multiple route response packets will result in excessive overhead control for a solitary route reply packet.
- It uses up more bandwidth because of regularly sending out beacons.

7.1.2.3 Temporally Ordered Routing Algorithm (TORA)

Temporally Ordered Routing Protocol is a reactive and on demand routing protocol. TORA focuses on restricting control message dissemination within the extremely fluid Ad-hoc networks. In TORA, the node clearly starts a query when it needs to transmit data to the destination. TORA duties involve managing the route, establishing the route from start to finish, and deleting the route when it is no longer useful, utilizing QRY for creation, UPD for maintenance, and CLR for deletion. TORA reduces the amount of communication overhead during topology changes. Because the route reply message is disseminated by neighbors exclusively when the message originates at a higher level and descends to a lower level in the tree, it forms a tree-like configuration. It is effective in dynamic Ad-hoc networks. TORA outperforms DSR in network performance [39].

The advantages of TORA

- TORA is applied to deal topology changes network.
- Multiple paths created.
- Good in dense networks.
- That of an on-demand routing protocol, it creates a directed acyclic graph (DAG) only when necessary.

The disadvantages of TORA

- Same as on-demand routing protocols.
- Not much used since DSR and AODV outperform TORA.
- Not scalable by any means.

7.1.3 Hybrid Routing Protocols

Hybrid ad hoc routing protocols divide the network into two regions: local and global. In order to improve efficiency and scalability, the zone routing proactive routing protocol (ZRP) combines local reactive routing protocols with global protocols to reduce routing overhead and delay caused by route discovery. Both strategies must be combined to maintain the current routing paths of networks, as they restrict changes in topology over a specified period of time [33].

The advantages of ZRP

- Higher efficiency & scalability.

The disadvantages of ZRP

- High latency for finding new routes.

7.2 Position-Based routing protocols

Geographical coordinates of nodes are required by this routing protocol in order to transmit information to additional nodes [42]. It essentially employs a GLOBAL POSITIONING SYSTEM (GPS) device to identify the location (geographical coordinates) of nearby nodes. If a source node wants to send a data packet to a target node, it simply needs to include the destination's position in the header of the packet. To forward packets, locate the target node's position and then send the data packet to it. Position-based routing is ideal for environments with high mobility, as it does not rely on routing tables or the need for route maintenance or discovery information. This routing protocol has a disadvantage as the GPS device stops working in tunnels and causes the location server to get stuck in a deadlock state. Some examples of position-based routing protocols include DREAM (Distance Routing Effect Algorithm for Mobility) and GPSR (Greedy Perimeter Stateless Routing) [43, 44].

7.2.1 Distance Routing Effect Algorithm for Mobility (DREAM)

As cited in reference [40], GPS is utilized by each node within the DREAM system to establish its position. Following this, the positions of the nodes are swapped and saved in a table for locations. Moreover, the rate at which updates and location exchanges occur is connected to topology changes caused by nodes moving. Therefore, whenever an update is needed, each node creates a location packet and spreads it throughout the network to share its location information. DREAM relies on a pair of algorithms. The initial algorithm relies on flooding to distribute location packets, while the second algorithm is utilized for disseminating data packets.

7.2.2 Greedy Perimeter Stateless Routing (GPSR)

GPSR operates utilizing a greedy routing algorithm. Therefore, a source node transmits a data packet through multiple intermediate nodes before reaching the destination. Furthermore, this algorithm relies on a stateless routing algorithm to gather details about a node's first hop neighbors [41].

7.2.3 Routing information protocol (RIP)

The final protocol covered in this group is RIP, created to address the issue of multiple links failures. This protocol determines the vehicle's speed and direction of movement. Following that, every node maintains a routing table with details on neighbors' locations and velocities. Therefore, the source node chooses a close neighbor based on the information in its table until it reaches the destination. Therefore, it can be inferred that the criteria for choosing the next hop node assists in the improved selection of other intermediate nodes required for subsequent hops by considering position and movement speeds. [45]. Position based routing advantages and disadvantages are:

Advantages

- Suitable for highway environment
- It is not required for global routes.
- It considers high stability in high mobility environment.

Disadvantages

- Location server sometime goes into deadlock state.
- (GPS) is always needed.
- GPS fails to work in the tunnel.

7.3 Cluster based routing protocol

The term clustering in vehicular ad hoc network refers to dividing the dynamic nodes into different groups. A cluster is recognized by a group of nodes as part of themselves. A specific node, known as the cluster-head, oversees routing, relaying inter-cluster traffic, managing intra-cluster traffic, and assigning channels for cluster members. Cluster-based routing is the chosen method within clusters. A cluster of nodes state their membership and a node acting as the cluster head sends the packet to the cluster. Highly mobile VANETs may experience network delays and overhead while forming clusters, although good scalability is possible for large networks. Cluster-based routing requires the formation of a virtual network infrastructure by grouping nodes together to ensure scalability [3].

7.3.1 Cluster Based Routing (CBR)

The researchers proposed in [48] introduced a novel class of VANET routing protocols known as Cluster Based Routing (CBR). These protocols involve categorizing the nodes in the network into clusters. Therefore, neighboring nodes come together to create a cluster where one vehicle is chosen as the head of the cluster. The cluster's size changes based on the criteria employed for its formation. This means that the network can be divided into clusters based on the number of vehicles, their location, and their movement speed and direction. Following this, nodes in a cluster select a cluster head that will oversee the cluster to facilitate inter-cluster communication. Therefore, the optimal neighboring cluster is chosen to transmit data during inter cluster communication [46, 47].

7.3.2 Location-Based Routing Algorithm

The LORA-CBF algorithm is founded on the division of network nodes into clusters. Following that, every cluster will be assigned a cluster head which will oversee communicating with other clusters and cluster heads. Additionally, cluster heads transmit regular beacon messages to update their parameters. Moreover, cluster heads send location request packets to gather location data from other clusters. This routing protocol, developed to enhance V2V communication, is worth noting [48].

Advantages

- It exhibits strong scalability in handling extensive networks.
- Latencies in extremely fast-moving networks.

Disadvantages

- There is a rise in network overheads.

7.4 Geocast/ Multicast Routing Protocol

The Geocast/Multicast routing protocol sends information to a group of nodes within a specific geographical area. It relies on sending the information or data packet directly to a specified area known as the forwarding zone. Geocast routing is essentially a multicast routing based on location, with the goal of sending data from one node to all other nodes in a specific geographic area known as a Zone of Relevance (ZOR) [8][33]. A designated area called a Zone of Forwarding (ZOF) is identified, where packets are specifically directed instead of being sent to all areas of the network. In Geo cast routing, vehicles located outside the ZOR are not notified to prevent unnecessary immediate response. Geo cast is recognized as a multicast service that operates within a designated geographic area [5][6]. It typically sets up a forwarding zone to control how packets are flooded, aiming to decrease message overhead and network congestion resulting from unrestricted packet flooding [1]. MOBICAST, DRG [51], VADD, and GROOV are listed as routing protocols in this category [52][53].

7.4.1 ROVER (RObust VEhicular Routing)

The method relies on employing flooding to distribute control packets. However, unicast is utilized for transmitting data messages. This protocol relies on segmenting the network into pertinent zones. Following that, a vehicle will only receive a message if it was sent while the vehicle was within that specific zone [49][54].

Advantages

- Minimized network burden and traffic jams.
- Dependable packet delivery in extremely fluid network structure.

Disadvantages

- Network disconnection causes delays in packet transmission.

7.5 Broadcast based routing protocols

This routing protocol is frequently utilized in VANETs, especially in safety applications. When in broadcast mode, a packet is transmitted to every node in the network, even those that are unknown or unspecified, and each node then retransmits the message to other nodes in the network. Flooding is a popular method employed in broadcast routing protocols [25]. Nonetheless, blind flooding leads to the issue of broadcast storm. A broadcast storm may overwhelm the restricted channel capacity, resulting in channel congestion that decreases communication reliability [33]. Broadcast routing is commonly employed in VANET to share information such as traffic, weather, emergency situations, road conditions between vehicles and for sending advertisements and announcements. The different Broadcast routing protocols include BROADCOMM, UMB, VTRADE, and DV-CAST [50].

7.5.1 BROADCOMM Routing Protocol

The highway network of BROADCOMM relies on a hierarchal structure. Within BRAODCOMM, the virtual cells within the highway mimic the movement of vehicles. The highway nodes are structured in a two-level hierarchy: the initial level comprises all nodes within a cell, while the second level consists of cell reflectors, a small number of nodes situated near the geographic center of the cell. Cell acting as cluster head processes emergency messages from cell members or close neighbors for a specified period of time. This protocol performs similar to flooding base routing protocols for message broadcasting and routing overhead.

7.5.2 Dynamic gradient routing protocol (DGR)

The DGR protocol was created using the gradient routing protocols as a foundation [55][56]. In gradient routing protocols, every node possesses a gradient (commonly the cost of data transmission), indicating the path towards the sink. Data packets are sent in the direction of the decreasing gradient to ensure the data is forwarded towards the sink. In most current gradient-based routing protocols, the gradient field remains constant from the start and is not altered throughout the routing process to reduce overhead.

Advantages

- Because the packet is sent through multiple nodes, the transmission of the packet is dependable.
- Reduce excess by preventing broadcast storm incidents.

Disadvantages

- Use up a vast quantity of network bandwidth.

8. DISCUSSION OF ROUTING IN CELLULAR NETWORKS (4G/5G)

The idea of Ad hoc networks was initially known as NTDR (Near Term Digital Radio) in the early 1990s before expanding into bigger groups of networks with hundreds of devices linked to relay or intermediate devices [87,88]. The D2D communication networks in 5G IoT networks are the ones that support this device. Because this network does not rely on the previous infrastructure, intermediate relays have the ability to form their own connections and connect with devices. The technology does not have a set position for the devices, but there is some level of flexibility when compared to their original position. The protocols are in charge of ensuring proper routing to target devices constantly to maintain uninterrupted performance and meet QoS expectations [59–62]. The issue with D2D communication lies in the mobile devices' limited battery resources. Because of this, it is crucial to prioritize energy efficiency in order to maintain the performance of the network. Various approaches have been implemented to conserve energy, such as limiting data to clusters or staying within the routing metric [63-65]. Nevertheless, there are multiple approaches to achieving energy savings in one direction. Consistently taking the identical route while transitioning between locations will impact both the battery's effectiveness and the device's overall battery longevity. An inherent drawback of single path protocols is susceptible to node failures, mostly due to the quick drainage of the node's battery. The restriction happens when certain nodes are heavily congested and handle the majority of network traffic, while other nodes are not part of the routing process [95]. When the node battery runs out in the established path, the path is no longer accessible, and a new alternative path must be found for data transmission. A way to address this problem is to send the message through multiple paths at the same time [66].

Researchers have been examining various aspects of routing protocols for numerous years, as well as exploring multiple wireless networking solutions that offer dependable communication, distribute data packets evenly, and enhance QoS performances [67–74]. Multipath routing is a new technique that reduces latency, lowers control packet overhead, and extends the lifespan of networks. There are multiple methods to enhance this network's performance by enabling devices to resolve loading issues between different locations. The goal of routing in D2D communication is to establish a path that is efficient, stable, robust, and reliable between source and destination devices. However, scientists worldwide are focusing on improving network performance by optimizing energy resources, ensuring network and route stability, addressing data packet traffic congestion, and overcoming link quality constraints of devices [75–78].

Obstacles encountered when choosing routes in D2D communication over IoT 5G networks include energy resource usage, network and route instability, data packet congestion, and link quality limitations of devices.

8.1 Data packets traffic congestion constraint

A drawback of D2D communication in IoT B5G networks is the congestion of data packets on the network devices. Excessive packets flooding a single mobile device, causing a high amount of network traffic, can lead to delays in data transmission within the network. Because of this, the routing schemes experience difficulties in distributing the workload evenly among the relay devices, leading to a significant decrease in the overall network performance.

In the wireless network, there is a connection between the energy usage of network devices and collisions in data packet traffic, as mentioned in [79]. A wireless network protocol called energy-efficient and collision-aware (EECA) node disjoint multipath routing protocol addresses this issue. The flooding of route discovery packets is restricted to the neighbor's device where the route has been found.

Advantages
- Offers substantial improvements in network performance, energy efficiency, and efficient data transfer.

Disadvantages
- Traffic on various routes will disrupt each other.

An examination of Quality OLSR (Q-OLSR) multipath routing in wireless networks based on various metrics like bandwidth and delay for selecting paths. Their technique provides load balancing and improves overall throughput, making it suitable for wireless network routing. However, the plan does not account for scalability with various communication capabilities and several radio interfaces [80].

Advantages
- Provide load distribution, reduce overall delay, and improve data transfer rates.

Disadvantages
- Not distinguished by various communication abilities and numerous radio interfaces.

The HOLSR method is used in large, diversified wireless networks for routing. The hierarchical network structure takes advantage of multiple interfaces created at different logical levels within the network topology. Using various interfaces, the HOLSR protocol reduces control packet overhead and improves the routing scheme performance of the network [81].

Advantages
- Minimize control overhead and enhance the efficiency of routing calculations.

Disadvantages
- Causes network instability, leading to a decrease in network performance.

Routing for mobile wireless networks is done through Multipath-OLSR (MPOLSR). The suggested routing scheme can handle scalability, security, network privacy, lifespan, and wireless transmission issues through adaptation to wireless network applications [82].

Advantages
- Handling the scalability, security, network privacy longevity, and wireless transmission fluctuations

Disadvantages
- Limited to stationary wireless networks.

Implementing a Proactive Source Routing technique to enable data packets to be forwarded opportunistically on wireless networks. Every device store full topological network details and regularly communicates with neighboring devices [83].

Advantages
- Decreases the load of routing and enhances the capacity for transmitting data.

Disadvantages
- Fails to take into account the network's cross-layer overhead.

Least Common Multiple based Routing (LCMR) is a method used in wireless networks to evenly distribute the traffic across different possible routes. The suggested routing method effectively handles and distributes data packets to reduce route discovery time for the route selection process [84].

Advantages
- Minimize the overall routing time and improve QoS performances

Disadvantages
- Limited to the specific network and flexibility is necessary in the heterogeneous network.

Ref. [85] suggested a protocol named Energy-harvesting-aware routing algorithm (EHARA) for diverse IoT networks, along with the incorporation of the 'energy backoff' parameter. This approach can address the challenges related to balancing the load and optimizing energy usage in network devices.

Advantages

- Equally distribute the workload and minimize the power usage of the network equipment.

Disadvantages

- Control overhead needs to be significantly reduced before it can be implemented in practical networks

In Ref. [86], the writers suggested a Spectrum aware Energy-Efficient multipath routing strategy for D2D communication in IoT mesh networks known as SpEED-IoT. The researchers utilized radio environment maps in the multipath routing method to determine the optimal route and effective channel usage among devices. The SpEEDIoT method employed a selective flooding strategy to reduce the impact of flooding from route discovery messages in the network, leading to a decrease in energy consumption by the devices.

Advantages

- Enhance network data rate efficiency, mitigate flooding impact, and decrease energy usage.

Disadvantages

- The MAC layer collision happens when data packets are sent at the same time on different paths.

8.2 Limitations on network reliability

The position of the mobile device within the D2D communications network is constantly changing, leading to corresponding changes in the network's topology. Designing the routing protocol to improve network throughput requires effectively managing network maintenance and route stability [87, 88–90].

In [91], a protocol called Energy aware Multipath Routing Protocol (EMRP) is introduced. It provides details about the physical and medium access control layers to assess the energy resources and link bandwidth of devices, allowing it to select the best path. So, the EMRP extends the lifespan of the network and enhances the connection of links.

Advantages

- Extends the lifespan of the network and enhances the connectivity of links.

Disadvantages

- Flat routing scheme's scalability.

Ref. [92] introduced an alternative form of OLSR known as Heterogeneous OLSR (H-OLSR) to address the scalability issue associated with a flat routing approach. The H-OLSR protocol decreases the number of topological control overhead messages in the network due to the frequent changes in network topology, such as HELLO and TC packets. The H-OLSR scheme makes use of the best, trustworthy connection between nodes for effective data packet delivery. This suggested routing plan can enhance wireless network performance by improving network performance, offering multi-channel radio for improved communication, and radio connectivity. On the other hand, this idea does not function effectively with the portable version of the gadget.

Advantages

- Enhanced rate of packet delivery, decreased route calculation expenses, and decreased network latency.

Disadvantages

- The plan does not function well in scenarios with high device mobility.

In Ref. [93], the author suggested an Optimized Polymorphic Hybrid Multicast Routing (OPHMR) strategy to reduce network overhead by introducing three new ideas: hybridization, adaptability, and power awareness. The suggested routing method offers flexible energy management and multi-behavior operation of devices in high mobility network scenarios. OPHMR combines reactive and proactive routing based on demand, extending battery life, reducing latency, and improving packet delivery success in the network.

Advantages

- Extended the node's battery lifespan, decreased latency, and improved the likelihood of successful packet delivery in the network.

Disadvantages

- Choosing one specific route can be easily disrupted and must be found again due to the ever-changing structure of networks.

An energy-efficient network is achieved by utilizing a routing strategy that combines ant colony meta-heuristic and swarm intelligence. The routing scheme being presented uses a self-configuration mechanism that handles and adjusts the network configuration based on changes in the network's topology and geography. According to the ants' current behavior, they roam independently in a small region instead of sharing their remaining battery level with other devices. The suggested plan takes into account the necessary battery power for sending packets on the route and chooses the best routing method based on the estimated data [94].

Advantages

- Mobility-conscious disjoint routing paths achieve network resilience.

Disadvantages

- Approach for measuring mobility and selecting routes based on points is not included in individual device mobility.

8.3 Limitations in energy resources

In IoT B5G networks, mobile devices have restricted energy resources for essential data transmission during D2D communication. Once the device runs out of energy, its connectivity will be affected by packet drops. The limited processing power and energy resource restrictions are major obstacles in creating an efficient path, which negatively affects the network's lifespan.

The OLSR reactive routing scheme was introduced in [95], wherein certain nodes act as Multi-Point Relay (MPR) to reduce topological control overhead messages in the network. MPRs are chosen based on neighboring nodes within two hops and greater energy reserves. Nevertheless, the frequent use of MPRs in the chosen path causes the MPRs' battery to quickly deplete, leading to communication breakdown between nodes.

Advantages

- Reduce the excessive flow of packets in the network, especially effective for extensive and crowded networks.
- Offers the best possible paths with the fewest number of device hops.

Disadvantages

- Regular use of MPRs in the chosen path causes rapid depletion of the MPRs battery, leading to link failure between nodes.

EMRP, a Multipath Routing Protocol, was presented in [91], allowing network nodes to share both their remaining energy levels and topological information with each other. Thus, the nodes will make use of the remaining energy of all nodes in the selected route when choosing the optimal routes. The EMRP protocol extends the longevity of the network, reduces energy usage, and boosts the packet delivery rate. However, the single route can be easily disrupted and must repeat the route discovery process due to frequent changes in the network topology, leading to packet flooding and data transmission delays.

Advantages

- Extend the lifespan of the network, reduce energy usage, and enhance packet delivery rates.

Disadvantages

- The one route can be easily disrupted, and finding the path again results in more delay and higher control overhead packets because of the ever-changing structure of networks.

The authors in [96] applied swarm intelligence to present the Ant based Energy-Aware Disjoint Multi-Path Routing Algorithm (AEADMRA), which includes "devices energy consumption" as a factor in device selection for the route. The routing scheme used the concept of swarm intelligence, where ants work together to solve complex problems. The AEADMRA discovers numerous energy-efficient routing paths with minimal routing overhead using swarm intelligence, particularly focusing on the ant colony-based meta-heuristic. The findings showed that the proposed plan reduced the routing complexity and enhanced the route discovery mechanism.

Advantages

- Simplify route selection and enhance the route discovery procedure.

Disadvantages

- Bandwidth limitations are caused by the need to keep current network state information.

In their study [97], the authors suggest a proactive routing protocol in the wireless network that enhances energy efficiency and ensures accurate energy metrics. The authors have talked about a structure to enhance energy-efficient routing by introducing energy metrics into their study. The authors demonstrated in their research that the two techniques they suggested, prediction and smart prediction, successfully reduced energy level inaccuracies and maintained it across different traffic rates when compared to the basic OLSR protocol. Additionally, their suggested approach has increased accuracy across all levels of traffic load.

Ref. [98] proposed a LAER protocol that aims to reduce drain rate and energy consumption in distributed wireless networks. The LAER utilizes a shared metric and an adjusted perimeter forwarding method to recover from the local maximum. Their main goal was to improve the performance of device selection by increasing the duration of the links.

Advantages

- Enhance device selection efficiency by extending the duration of the link.

Disadvantages

- The focus of the work is solely on optimization formulation, with no mention of protocol analysis or performance management.

The authors introduced an Energy Efficient Preemptive DSR (EE-PDSR) in [99], a method for handling headers in order to reduce the control overhead associated with each data packet. The suggested method ensured that nodes transmit headers faster with minimal energy usage during data transmission, ultimately conserving energy across the network. The suggested plan reduces the amount of data traffic on the links and improves the links' capacity.

Advantages

- Reduce device power usage, decrease data processing duration, lower network traffic, and enhance channel capacity.

Disadvantages

- The study does not examine how scalable the QoS metric is or its quantitative accuracy level.

8.4 Link quality constraints

The mobile devices in D2D communication within IoT B5G networks move in an unforeseeable way, leading to a higher chance of link failure along the route between source and destination devices. Because of the connection problem in the existing path, the data packet must be sent again using a different connection, resulting in increased bandwidth usage in the network.

The article [100] introduced a Quality OLSR routing (QOLSR) that selects routes based on performance metrics like bandwidth and delay. The paths are free from loops and have several separate nodes, calculated by utilizing the shortest-path algorithm. Furthermore, a correlation factor is implemented to examine the quantity of connections between each pair of separate paths.

Advantages

- Reducing the interferences among various routes enhanced QoS performance by optimizing network resource utilization.

Disadvantages

- No analysis and evaluation have been done on the protocol management and performance, with the focus solely on optimization formulation issues.

In order to ensure the network is dependable and stable, a method known as LIA-MPOLSR was introduced [101]. The LIA-MPOLSR suggested a revised routing method that incorporates OLSR. This suggested plan can accurately assess the link quality between nodes prior to transmitting data to enhance the likelihood of successful packet delivery within the network.

Advantages

- It results in reduced routing overhead and standardizes routing load.

Disadvantages

- Appropriate for situations with fixed network structures where devices remain stationary.

In [102], a different method was suggested which improves the multipath Dijkstra algorithm to discover numerous paths in a congested and scattered network, termed as the MP-OLSR routing approach. The MP-OLSR scheme utilizes two cost metrics to form node disjoint and link disjoint paths.

Advantages

- Offer enhanced flexibility across different link cost metrics and cost functions.
- Increase the likelihood of successful packet delivery and decrease the likelihood of broken links.

Disadvantages

- Does not take into account the mobility of devices when selecting paths or MPRs.

In article [103], the authors introduced the Link-stability and Energy-Aware Routing scheme (LAER), which selects routes based on both link stability and energy drain rate. An optimization technique called Biobjective Integer Programming is used to improve link stability and reduce energy consumption in the path computation process. The LAER strategy prolongs the network's lifespan and ensures network stability.

Advantages

- Extends the network lifetime and/ maintains network stability

Disadvantages

- It does not use link-state evaluation criteria for device energy and iterative factors to find several parallel disjoint routes.

Meanwhile, the researchers in [104] proposed a Disjointed Multipath Routing (DMP_EOLSR) system utilizing OLSR in wireless networks. The method takes into account the lifespan of devices and links based on their energy usage and mobility mode, respectively. The authors propose in their paper that they have alleviated broken links to improve network stability.

Advantages

- Lessen broken links to improve the stability of the network.

Disadvantages

- The lifespan of links always depends on the real-time location of the neighboring device, which may not be constantly accessible.

Ref. [105] introduces the MOLSR routing scheme as a variation of OLSR, to address the average end-to-end delay by enhancing the path discovery and path computation process of OLSR routing. The method being suggested chooses the nearby device depending on the greater amount of energy and improved link quality.

Advantages

- Attain balance in data traffic distribution and ensure equitable energy distribution across network devices

Disadvantages

- Increased time to find an alternative route in case of a link failure

Frequent changes in the network topology result in poor link quality among nodes, causing frequent breaks in connections within the multi hop network. In [106], a new routing approach called Smooth Mobility and Link Reliability-based on OLSR (SMLR-OLSR) is presented to tackle this problem. The use of Semi-Markov/ Smooth and Complexity Restricted mobility models helps to enhance flexibility, reduce complexity, optimize MPR selection process, extend MPRs lifespan, and reduce routing control packets overhead in multi-hop wireless networks.

Advantages

- Extend the lifetime of Prologs MPRs and reduce the overhead of routing control packets in the multi-hop network.
- Does not excel in situations involving device mobility.

8.5 Key performance metrics

To provide a comprehensive understanding, this paper presents a comparative analysis of routing protocols in VANETs and cellular networks. The comparison evaluates key performance metrics such as packet delivery ratio (PDR), packet loss, end-to-end delay, scalability, and reliability, offering insights into the strengths and weaknesses of each protocol in different scenarios. Table 1 shows a comparison of routings for different features related to VANET routing protocols and cellular routing protocols. Figure 7 shows a comparison represented in Table 1.

Table 1:Comparison of ad-hoc and cellular routing networks

Feature	VANET Routing Protocols	Cellular Network Routing Protocols	Reference
Topology	Dynamic and unpredictable	Relatively stable	[107, 108]
Routing Metric	Hop count, delay, energy efficiency	Hop count, link quality, load balancing	[109, 110]
Routing Algorithm	Reactive, proactive, hybrid	Fixed routing tables, dynamic routing protocols	[111, 112]
Packet Delivery Ratio	Lower due to frequent topology changes	Higher due to stable network conditions	[113, 114]
Latency	Higher due to frequent route discovery and re-routing	Lower due to fixed routing tables	[115, 116]
Energy Efficiency	Critical due to limited battery power	Less critical due to fixed infrastructure	[117, 118]
Security	Vulnerable to various attacks (e.g., black hole, wormhole)	More secure due to infrastructure-based security mechanisms	[119, 120]
Scalability	Can scale to large networks but faces challenges in maintaining network connectivity	Scales well due to established infrastructure	[121, 122]
Quality of Service (QoS)	Difficult to guarantee QoS due to dynamic topology and interference	Can provide guaranteed QoS through resource allocation and prioritization	[123, 124]

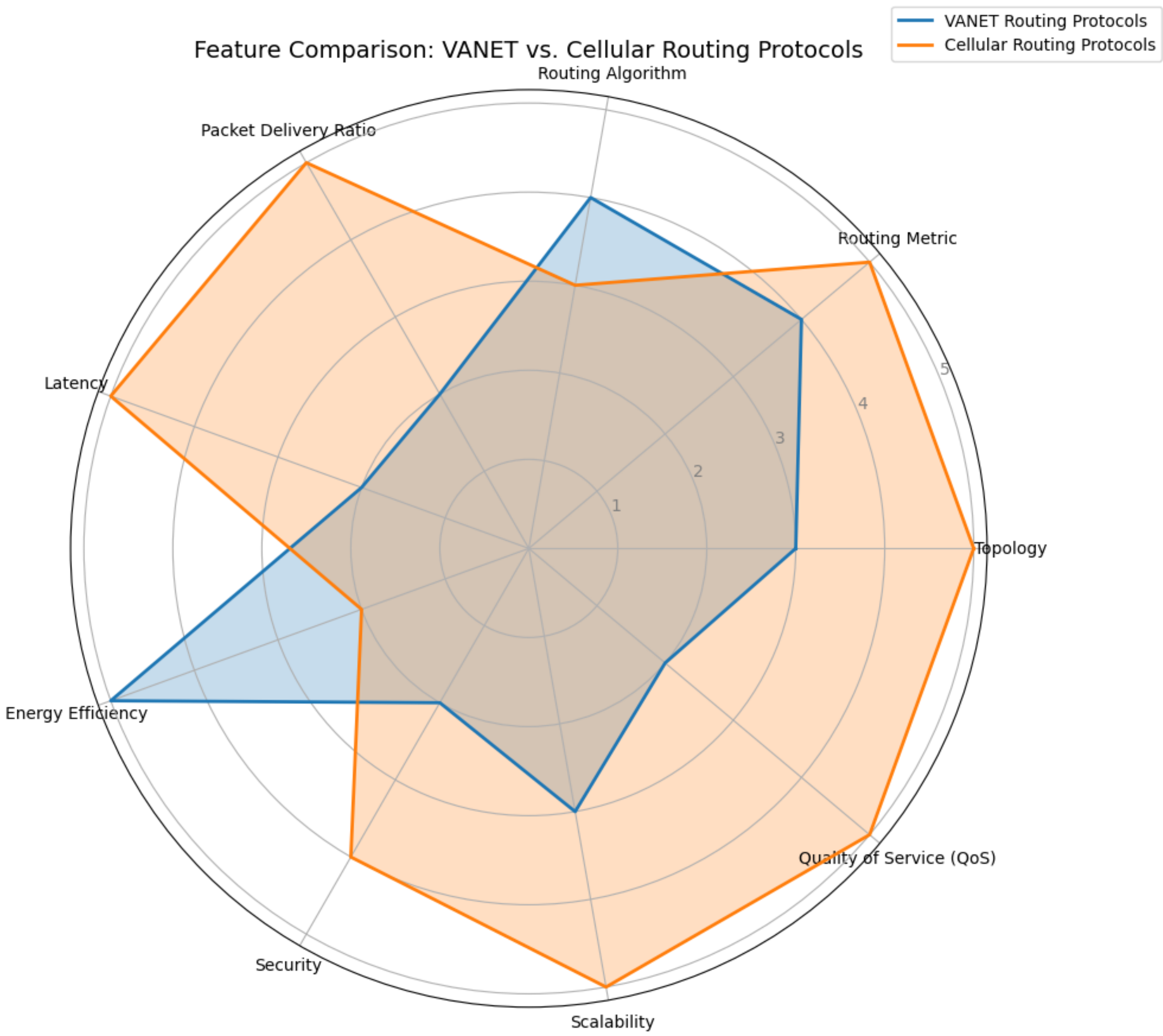

Figure 7: **VANET VS. Cellular routing protocol**

9. CONCLUSIONS

The swift progress in Vehicular Ad Hoc Networks (VANETs) offers groundbreaking possibilities to transform transportation by improving road safety, streamlining traffic flow, and facilitating smart communication systems. This study was inspired by the urgent requirement to tackle significant issues related to VANETs, including changing topology, intense mobility, and effective data distribution, which are essential for realizing dependable and secure vehicular communication networks.

This research sought to deliver an in-depth insight into the routing protocols used in VANETs, emphasizing their effectiveness in fluid and distributed settings, while also comparing these with the more consistent communication structures provided by cellular networks. By examining topology-based, geo-based, and cluster-based routing protocols, the study highlighted their distinct strengths and weaknesses regarding packet delivery, latency, and adaptability to rapid topology modifications.

The results indicate that although VANETs provide unique flexibility and adaptability, their effectiveness is frequently hindered by significant packet loss and regular disconnections. Cellular networks, on the other hand, offer more reliable communication but encounter difficulties in densely populated or isolated locations. These findings emphasize the opportunity for hybrid models or combined frameworks that utilize the advantages of both VANETs and cellular networks to overcome their individual shortcomings.

By grasping these trade-offs, this study aims to inform future research in creating innovative solutions that enhance the functionalities of VANETs and facilitate their smooth incorporation into the changing realm of intelligent transportation systems.

9.1 Future Directions

To address the persistent challenges in VANETs, future research can focus on developing more robust and adaptive solutions tailored to the dynamic and decentralized nature of vehicular networks. Below are detailed directions with specific examples and potential applications:

- **AI-Driven Routing Algorithms**: Example: Develop machine learning models that predict traffic congestion and dynamically adjust routing protocols in real time. For instance, Google's traffic prediction systems or Tesla's autonomous navigation can inspire AI integration into VANET routing for optimizing routes based on historical and live traffic data.
  - Case Study: Implement AI-based routing in smart cities like Singapore or Dubai, where advanced infrastructure supports the deployment of VANET-enabled autonomous vehicles. Measure performance improvements in reducing traffic congestion and accidents.
- **Integration with 5G and Beyond:** Example: Leverage 5G's ultra-reliable low-latency communication (URLLC) to support autonomous vehicle platooning, where groups of vehicles maintain synchronized movement to optimize fuel efficiency and traffic flow.
  - Case Study: Conduct pilot projects in regions deploying 5G, such as South Korea or Germany, to test VANET integration with cellular networks in high-density traffic scenarios.
- **Blockchain for Security and Privacy:** Example: Utilize blockchain to create tamper-proof logs of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, ensuring data authenticity and preventing malicious attacks.
  - Case Study: Implement blockchain-enabled VANETs in areas prone to cybersecurity threats, such as major financial hubs or regions with high levels of autonomous vehicle adoption. Test its ability to mitigate security risks in real-world conditions.
- **Hybrid Networking Models:** Example: Design a hybrid framework combining ad hoc communication for local traffic updates and cellular networks for wide-area coverage. This can ensure uninterrupted connectivity during emergencies or in rural areas with sparse infrastructure.
  - Case Study: Test hybrid models in areas like California, USA, where both urban and rural regions coexist, ensuring effective communication in diverse environments.
- **Vehicular Edge Computing (VEC):** Example: Deploy edge nodes at traffic intersections to process real-time data from vehicles, such as collision warnings or pedestrian detection, reducing decision-making latency.
  - Case Study: Conduct trials in smart cities like Amsterdam, using VEC to improve safety at busy intersections and measure the reduction in response times during critical events.
- **Environmental Considerations:** Example: Develop energy-efficient routing protocols, such as those minimizing the use of idle communication, to reduce the carbon footprint of VANET-enabled systems.

  - Case Study: Deploy these protocols in environmentally conscious regions like Scandinavia, where green technology goals align with sustainable transport initiatives.

- **Interoperability with IoT:** Example: Integrate VANETs with IoT devices like smart traffic lights, weather sensors, and parking systems to create a unified transportation ecosystem.

  - Case Study: Use IoT-integrated VANETs in metropolitan areas like New York City to enable seamless communication between vehicles and urban infrastructure, improving traffic flow and reducing travel times.

- **Real-World Testing and Simulations:** Example: Develop advanced simulation environments, such as using SUMO or Veins, to evaluate routing protocols under diverse traffic conditions and urban layouts.

  - Case Study: Conduct field trials on dedicated testbeds like Michigan's Mcity or China's autonomous vehicle zones to validate theoretical models and assess protocol efficiency in real-world scenarios.

REFERENCES

[1] Singh, P. K., Gowtham, S. N., Tamilselvan, S., & Nandi, S. (2019). CPESP: Cooperative pseudonym exchange and scheme permutation to preserve location privacy in VANETs. Vehicular Communications, 20, 100183.
[2] Wang, J., Zhang, H., Tang, X., & Li, Z. (2020). Delay-tolerant routing and message scheduling for CR-VANETs. Future Generation Computer Systems, 110, 291-309.
[3] Paul, B., & Islam, M. J. (2012). Survey over VANET routing protocols for vehicle-to-vehicle communication. IOSR Journal of Computer Engineering (IOSRJCE), 7(5), 1-9.
[4] Ziyadinov, V. V., & Tereshonok, M. V. (2020, July). Analytical survey on manet and vanet clusterisation algorithms. In 2020 Systems of Signal Synchronization, Generating and Processing in Telecommunications (SYNCHROINFO) (pp. 1-5). IEEE.
[5] Wahid, I., Ikram, A. A., Ahmad, M., Ali, S., & Ali, A. (2018). State of the art routing protocols in VANETs: A review. Procedia computer science, 130, 689-694.
[6] S. Vodopivec, J. Bester, and A. Kos, "A survey on clustering algorithms for vehicular ad-hoc networks," in 2012 35th International Conference on Telecommunications and Signal Processing (TSP), 2012, pp. 52–56.
[7] Huang, C. M., Lin, S. Y., & Wu, Z. Y. (2020). The k-hop-limited V2V2I VANET data offloading using the Mobile Edge Computing (MEC) mechanism. Vehicular Communications, 26, 100268.
[8] Khan, Z., Fan, P., Abbas, F., Chen, H., & Fang, S. (2019). Two-level cluster-based routing scheme for 5G V2X communication. IEEE Access, 7, 16194-16205.
[9] Wahid, A. A. Ikram, M. Ahmad, S. Ali, and A. Ali, "State of the Art Routing Protocols in VANETs: A Review," Procedia Computer Science, vol. 130, pp. 689-694, 2018/01/01/ 2018.
[10] M. S. Talib, B. Hussin, and A. Hassan, "Converging VANET with vehicular cloud networks to reduce the traffic congestions: A review," Int. J. Appl. Eng. Res., vol. 12, no. 21, pp. 10646–10654, 2017.
[11] F. Cunha et al., "Data communication in VANETs: Protocols, applications and challenges," Ad Hoc Networks, vol. 44, pp. 90–103, Jul. 2016.
[12] Tahir MN, Leviäkangas P, Katz M. Connected Vehicles: V2V and V2I Road Weather and Traffic Communication Using Cellular Technologies. Sensors. 2022; 22(3):1142. https://doi.org/10.3390/s22031142.
[13] Bonjorn, N., Foukalas, F., & Pop, P. (2018, June). Enhanced 5G V2X services using sidelink device-to-device communications. In 2018 17th annual mediterranean ad hoc networking workshop (Med-Hoc-Net) (pp. 1-7). IEEE.
[14] Tembhare, S., & Mishra, A. (2019). Review on Security of Information Dissemination and Various Protocols in the Internet-of-Vehicles. International Journal on Recent and Innovation Trends in Computing and Communication, 7(6). https://doi.org/10.17762/ijritcc.v7i6.5315
[15] Azam, F., Yadav, S. K., Priyadarshi, N., Padmanaban, S., & Bansal, R. C. (2021). A comprehensive review of authentication schemes in vehicular ad-hoc network. In IEEE Access (Vol. 9). https://doi.org/10.1109/ACCESS.2021.3060046.
[16] Senouci, O., Harous, S., & Aliouat, Z. (2020). Survey on vehicular ad hoc networks clustering algorithms: Overview, taxonomy, challenges, and open research issues. International Journal of Communication Systems, 33(11). https://doi.org/10.1002/dac.4402.
[17] Turcanu, P. Salvo, A. Baiocchi, and F. Cuomo, "An integrated VANET-based data dissemination and collection protocol for complex urban scenarios," Ad Hoc Networks, vol. 52, pp. 28–38, 2016.

[18] Achour, I., Alfayez, F., & Busson, A. (2021). A robust and efficient adaptive data dissemination protocol based on smart relay selection in vehicular networks. Wireless Networks, 27(7). https://doi.org/10.1007/s11276-021-02726-8.
[19] Loganathan, D., Balasubramani, M., & Sabitha, R. (2021). Energy Aware Efficient Data Aggregation (EAEDAR) with Re-scheduling Mechanism Using Clustering Techniques in Wireless Sensor Networks. Wireless Personal Communications, 117(4). https://doi.org/10.1007/s11277-020-07985-w.
[20] R. S. Hande and A. Muddana, “Comprehensive survey on clustering-based efficient data dissemination algorithms for VANET,” in International Conference on Signal Processing, Communication, Power and Embedded System, SCOPES 2016 - Proceedings, 2016, pp. 629–632.
[21] D. Agrawal and W. Arif, “Comprehensive Survey of V2V Communication for 4G Mobile and Wireless Technology,” in IEEE WiSPNET 2016 conference, 2016, pp. 1769–1773.
[22] K. A. Khaliq, A. Qayyum, and J. Pannek, “Methodology for Development of Logistics Information and Safety System Using Vehicular Adhoc Networks,” in Springer International Publishing Switzerland 2017, M. Freitag et al. (eds.), Dynamics in Logistics, Lecture Notes in Logistics, 2017, pp. 185–195.
[23] S. Al-Sultan, M. M. Al-Doori, A. H. Al-Bayatti, and H. Zedan, “A comprehensive survey on vehicular Ad Hoc network,” J. Netw. Comput. Appl., vol. 37, no. 1, pp. 380–392, 2014.
[24] Turcanu, P. Salvo, A. Baiocchi, and F. Cuomo, “An integrated VANET-based data dissemination and collection protocol for complex urban scenarios,” Ad Hoc Networks, vol. 52, pp. 28–38, 2016.
[25] L. A. Villas, A. Boukerche, G. Maia, R. W. Pazzi, and A. A. F. Loureiro, “DRIVE: An efficient and robust data dissemination protocol for highway and urban vehicular ad hoc networks,” Comput. Networks, vol. 75, no. PartA, pp. 381–394, 2014.
[26] L. A. Villas, A. Boukerche, H. S. Ramos, H. A. B. F. De Oliveira, R. B. De Araujo, and A. A. F. Loureiro, “DRINA: A lightweight and reliable routing approach for in-network aggregation in wireless sensor networks,” IEEE Trans. Comput., vol. 62, no. 4, pp. 676–689, 2013.
[27] T. Abdel-Halim and H. M. A. Fahmy, “Prediction-based protocols for vehicular Ad Hoc Networks: Survey and taxonomy,” Computer Networks, vol. 130. Elsevier B.V., pp. 34–50, 2018.
[28] H. S. Basheer and C. Bassil, “A review of broadcasting safety data in V2V: Weaknesses and requirements,” Ad Hoc Networks, vol. 65, pp. 13–25, 2017.
[29] P. S. Nithya Darisini and N. S. Kumari, “A survey of routing protocols for VANET in urban scenarios,” in Proceedings of the 2013 International Conference on Pattern Recognition, Informatics and Mobile Engineering, PRIME 2013, 2013, pp. 464–467.
[30] M. Slavik and I. Mahgoub, “Spatial distribution and channel quality adaptive protocol for multihop wireless broadcast routing in VANET,” IEEE Trans. Mob. Comput., vol. 12, no. 4, pp. 722–734, 2013.
[31] Vigilia and J. Suseela, “Survey on Unicast, Multicast and Broadcast Routing Techniques in Vehicular Adhoc Networks – Present and Future,” Br. J. Math. Comput. Sci., vol. 13, no. 4, pp. 1–26, 2016.
[32] Fonseca and T. Vazão, “Applicability of position-based routing for VANET in highways and urban environment,” J. Netw. Comput. Appl., vol. 36, no. 3, pp. 961–973, 2013.
[33] Turcanu, P. Salvo, A. Baiocchi, and F. Cuomo, “An integrated VANET-based data dissemination and collection protocol for complex urban scenarios,” Ad Hoc Networks, vol. 52, pp. 28–38, 2016.
[34] R. Ghebleh, “A comparative classification of information dissemination approaches in vehicular ad hoc networks from distinctive viewpoints: A survey,” Computer. Networks, vol. 131, pp. 15–37, 2018.
[35] L. A. Villas, A. Boukerche, G. Maia, R. W. Pazzi, and A. A. F. Loureiro, “DRIVE: An efficient and robust data dissemination protocol for highway and urban vehicular ad hoc networks,” Comput. Networks, vol. 75, no. PartA, pp. 381–394, 2014.
[36] G. Pei, M. Gerla, and T.-W. Chen, "Fisheye state routing: A routing scheme for ad hoc wireless networks," in Communications, 2000. ICC 2000. 2000 IEEE International Conference on, 2000, vol. 1, pp. 70-74: IEEE.
[37] T. Nebbou, M. Lehsaini, and H. Fouchal, "Partial backwards routing protocol for VANETs," Vehicular Communications, vol. 18, p. 100162, 2019/08/01/ 2019.
[38] X. Liu, Y.-m. Cheung, and Y. Y. Tang, "Lip event detection using oriented histograms of regional optical flow and low rank affinity puBaseit," Computer Vision and Image Understanding, vol. 148, pp. 153-163, 7// 2016.
[39] Y. Tao, X. Li, M. Tsukada, and H. Esaki, "Reliable Overlay Networking on ETSI GeoNetworking Standards," International Journal of Intelligent Transportation Systems Research, journal article pp. 1-14, 2017.
[40] Dutt, S., Agrawal, S., & Vig, R. (2021). Delay-Sensitive, Reliable, Energy-Efficient, Adaptive and Mobility-Aware (DREAM) Routing Protocol for WSNs. Wireless Personal Communications, 120(2), 1675-1703.
[41] Silva, A., Reza, K. N., & Oliveira, A. (2018, August). An adaptive GPSR routing protocol for VANETs. In 2018 15th International Symposium on Wireless Communication Systems (ISWCS) (pp. 1-6). IEEE.
[42] R. S. Hande and A. Muddana, “Comprehensive survey on clustering-based efficient data dissemination algorithms for VANET,” in International Conference on Signal Processing, Communication, Power and Embedded System, SCOPES 2016 - Proceedings, 2016, pp. 629–632.
[43] Sharma, S., & Sharma, P. (2019, May). Comprehensive study of various routing protocols in VANET. In 2019 International Conference on Intelligent Computing and Control Systems (ICCS) (pp. 1272-1275). IEEE.

[44] Talib, M. S., Hassan, A., Hussin, B., & Hassan, A. A. H. (2018). Vehicular ad-hoc networks: Current challenges and future direction of research. Jour Adv Res. Dyn. Control Syst, 10(2), 2065-2074.
[45] A. D. L. F. Y. Toor, P. Muhlethaler, A. Laouiti, “VEHICLE AD HOC NETWORKS: APPLICATIONS AND RELATED TECHNICAL ISSUES,” IEEE Commun. Surv., vol. 10, no. 3, pp. 74–88, 2008.
[46] Yogarayan, S., Razak, S. F. A., Azman, A., Abdullah, M. F. A., Ibrahim, S. Z., & Raman, K. J. (2020, June). A review of routing protocols for vehicular ad-hoc networks (VANETs). In 2020 8th International Conference on Information and Communication Technology (ICoICT) (pp. 1-7). IEEE.
[47] Vaiyapuri, T., Parvathy, V. S., Manikandan, V., Krishnaraj, N., Gupta, D., & Shankar, K. (2021). A novel hybrid optimization for cluster‐based routing protocol in information-centric wireless sensor networks for IoT based mobile edge computing. Wireless Personal Communications, 1-24.
[48] Poluboyina, L. (2021). A Comprehensive Simulation Study on the Multicast Operation of the AODV Routing Protocol for CBR Traffic in Mobile Ad-Hoc Networks. International Journal of Computer Networks and Applications, 8(6), 742-757.
[49] Lundell, D., Hedberg, A., Nyberg, C., & Fitzgerald, E. (2018, June). A routing protocol for LoRa mesh networks. In 2018 IEEE 19th International Symposium on" A World of Wireless, Mobile and Multimedia Networks"(WoWMoM) (pp. 14-19). IEEE.
[50] Zhang X, Lauber L, Liu H, Shi J, Wu J, Pan Y (2021) Research on the method of travel area clustering of urban public transport based on Sage-Husa adaptive filter and improved DBSCAN algorithm. PLoS ONE 16(12): e0259472. https://doi.org/10.1371/journal.pone.0259472.
[51] Kachooei, M.A., Hendessi, F., Ghahfarokhi, B.S. et al. An OLSR-based Geocast Routing Protocol for Vehicular Ad Hoc Networks. Peer-to-Peer Netw. Appl. 15, 246–266 (2022). https://doi.org/10.1007/s12083-021-01246-8.
[52] Dutta, D., Nayak, A. & Dutta, D. Reconnoitering the Usage of Agroindustrial Waste in Carotenoid Production for Food Fortification: a Sustainable Approach to Tackle Vitamin A Deficiency. Food Bioprocess Technol 16, 467–491 (2023). https://doi.org/10.1007/s11947-022-02888-z
[53] Daniel Simig, Fabio Petroni, Pouya Yanki, Kashyap Popat, Christina Du, Sebastian Riedel, and Majid Yazdani. 2022. Open Vocabulary Extreme Classification Using Generative Models. In Findings of the Association for Computational Linguistics: ACL 2022, pages 1561–1583, Dublin, Ireland. Association for Computational Linguistics.
[54] Maki, J.N., Gruel, D., McKinney, C. et al. The Mars 2020 Engineering Cameras and Microphone on the Perseverance Rover: A Next-Generation Imaging System for Mars Exploration. Space Sci Rev 216, 137 (2020). https://doi.org/10.1007/s11214-020-00765-9.
[55] Guo, Y., Xu, Zz., Chen, Cl. et al. DGR: dynamic gradient-based routing protocol for unbalanced and persistent data transmission in wireless sensor and actor networks. J. Zhejiang Univ. - Sci. C 12, 273–279 (2011). https://doi.org/10.1631/jzus.C1000184.
[56] Kang, D., Kim, H.-S., Joo, C., & Bahk, S. (2018). ORGMA: Reliable opportunistic routing with gradient forwarding for MANETs. Computer Networks, 131, 52–64. https://doi.org/https://doi.org/10.1016/j.comnet.2017.12.001.
[57] Malik, S., & Sahu, P. K. (2019). A comparative study on routing protocols for VANETs. Heliyon, 5(8), e02340
[58] Ma, Z., Li, B., Yan, Z., & Yang, M. (2020). QoS-Oriented joint optimization of resource allocation and concurrent scheduling in 5G millimeter-wave network. Computer Networks, 166, 106979.
[59] Yang, B., Wu, Z., Shen, Y., & Jiang, X. (2019). packet delivery ratio and energy consumption in multicast delay tolerant MANETs with power control. Computer Networks, 161, 150–161140.
[60] Lin, Z., & Wang, P. (2019). A review of data sets of short-range wireless networks. Computer Communications, 147, 138–158 141.
[61] Mei, H., Lu, H., & Peng, L. (2019). Data offloading in cache-enabled cross-haul networks. Computer Communications, 142, 1–8142.
[62] Wang, Y., Yu, Z., Huang, J., & Choi, C. (2019). A novel energy-efficient neighbor discovery procedure in a wireless self-organization network. Information Sciences, 476, 429–438.
[63] Zhao, Z., Xu, K., Hui, G., & Hu, L. (2018). An energy-efficient clustering routing protocol for wireless sensor networks based on AGNES with balanced energy consumption optimization. Sensors, 18(11), 3938144.
[64] Hasan, M. Z., Al-Rizzo, H., & Al-Turjman, F. (2017). A survey on multipath routing protocols for qos assurances in real-time wireless multimedia sensor networks. IEEE Communications Surveys & Tutorials, 19(3), 1424–1456. https://doi.org/10.1109/ COMST.2017.2661201145.
[65] Maheswar, R., et al. (2021). CBPR: A cluster-based backpressure routing for the internet of things. Wireless Personal Communications, 116, 1–19.
[66] Boushaba, A., Benabbou, A., Benabbou, R., Zahi, A., & Oumsis, M. (2014). An enhanced MP-OLSR protocol for MANETs. In 2014 International Conference on next Generation Networks and Services (NGNS), (pp. 73–79) 28–30 May 2014.2014, https://doi.org/10.1109/NGNS.2014.6990231.
[67] Gupta, L., Jain, R., & Vaszkun, G. (2016). Survey of important issues in UAV communication networks. IEEE Communications Surveys & Tutorials, 18(2), 1123–1152. https://doi.org/10.1109/ COMST.2015.2495297149.

[68] Pu, C. (2018). Jamming-resilient multipath routing protocol for flying Ad Hoc networks. IEEE Access, 6, 68472–68486. https:// doi.org/10.1109/ACCESS.2018.2879758150.
[69] Khalid, M., Ahmad, F., Arshad, M., Khalid, W., Ahmad, N., & Cao, Y. (2019). E2MR: energy-efficient multipath routing protocol for underwater wireless sensor networks. IET Networks, 8(5), 321–328. https://doi.org/10.1049/iet-net.2018.5203151.
[70] Valerio, V. D., Presti, F. L., Petrioli, C., Picari, L., Spaccini, D., & Basagni, S. (2019). CARMA: Channel-aware reinforcement learning-based multi-path adaptive routing for underwater wireless sensor networks. IEEE Journal on Selected Areas in Communications,37(11),2634–2647.https://doi.org/10.1109/ JSAC.2019.2933968152.
[71] Khalid, M., Cao, Y., Ahmad, N., Khalid, W., & Dhawankar, P. (2018). Radius-based multipath courier node routing protocol for acoustic communications. IET Wireless Sensor Systems, 8(4), 183–189. https://doi.org/10.1049/iet-wss.2017.0165153.
[72] Vinitha, A., & Rukmini, M. S. S. (2019). Secure and energy aware multi-hop routing protocol in WSN using Taylor-based hybrid optimization algorithm. Journal of King Saud University Computer and Information Sciences, 33(2021), 1–12154.
[73] Guirguis, A., Karmoose, M., Habak, K., El-Nainay, M., & Youssef, M. (2018). Cooperation-based multi-hop routing protocol for cognitive radio networks. Journal of Network and Computer Applications, 110, 27–42155.
[74] Geng, H., Shi, X., Wang, Z., & Yin, X. (2018). A hop-by-hop dynamic distributed multipath routing mechanism for link state network. Computer Communications, 116, 225–239.
[75] Lim, C. L., Goh, C., & Li, Y. (2019). Long-term routing stability of wireless sensor networks in a real-world environment. IEEE Access, 7, 74351–74360.
[76] Fu, X., Yao, H., & Yang, Y. (2019). Cascading Failures in Wireless Sensor Networks with load Redistribution of Links and Nodes. Ad Hoc Networks, 93, 101900.
[77] Abd-Elmagid, M. A., ElBatt, T., & Seddik, K. G. (2019). Optimization of energy-constrained wireless powered communication networks with heterogeneous nodes. Wireless Networks, 25(2), 713–730.
[78] Liu, X., Wen, Z., Liu, D., Zou, J., & Li, S. (2019). Joint source and relay beamforming design in wireless multi-hop sensor networks with SWIPT. Sensors, 19(1), 182.
[79] Wang, Z., Bulut, E. & Szymanski, B. K. (2009). Energy efficient collision aware multipath routing for wireless sensor networks. In Communications, 2009. ICC'09. IEEE International Conference on, pp. 1–5, IEEE.
[80] Badis, H. & Al Agha, K. (2004). QOLSR multi-path routing for mobile ad hoc networks based on multiple metrics: bandwidth and delay. vol. 4, pp. 2181–2184, IEEE.
[81] Villasenor-Gonzalez, L., Ying, G., & Lament, L. (2005). HOLSR: a hierarchical proactive routing mechanism for mobile ad hoc networks. IEEE Communications Magazine, 43(7), 118–125. https://doi.org/10.1109/MCOM.2005.1470838.
[82] Yi, J., Adnane, A., David, S., & Parrein, B. (2011). Multipath optimized link state routing for mobile ad hoc networks. Ad hoc networks, 9(1), 28–47.
[83] Wang, Z., Chen, Y., & Li, C. (2014). PSR: A lightweight proactive source routing protocol for mobile ad hoc networks. IEEE transactions on Vehicular Technology, 63(2), 859–868
[84] Bhattacharya, A., & Sinha, K. (2017). An efficient protocol for load-balanced multipath routing in mobile ad hoc networks. Ad Hoc Networks, 63, 104–114.
[85] Nguyen, T. D., Khan, J. Y., & Ngo, D. T. (2018). A distributed energy-harvesting-aware routing algorithm for heterogeneous IoT networks. IEEE Transactions on Green Communications and Networking, 2(4), 1115–1127.
[86] Debroy, S., Samanta, P., Bashir, A., & Chatterjee, M. (2019). SpEED-IoT: Spectrum aware energy efficient routing for device-to-device IoT communication. Future Generation Computer Systems, 93, 833–848
[87] Sharma, D., & Bhondekar, A. P. (2018). Traffic and energy aware routing for heterogeneous wireless sensor networks. IEEE Communications Letters, 22(8), 1608–1611. https://doi.org/10. 1109/LCOMM.2018.2841911.
[88] Song, M., & Zheng, M. (2018). Energy efficiency optimization for wireless powered sensor networks with nonorthogonal multiple access. IEEE Sensors Letters, 2(1), 1–4. https://doi.org/ 10.1109/LSENS.2018.2792454.
[89] Tang, L., Yang, X., Wu, X., Cui, T., & Chen, Q. (2018). Queue stability-based virtual resource allocation for virtualized wireless networks with self-backhauls. IEEE Access, 6, 13604–13616. https://doi.org/10.1109/ACCESS.2018.2797088
[90] Vu, T. K., Bennis, M., Debbah, M., & Latva-Aho, M. (2019). Joint path selection and rate allocation framework for 5G self-backhauled mm-wave networks. IEEE Transactions on Wireless Communications, 18(4), 2431–2445. https://doi.org/10.1109/ TWC.2019.2904275.
[91] Li, M., Zhang, L., Li, V. O., Shan, X., & Ren, Y. (2005). An energy-aware multipath routing protocol for mobile ad hoc networks. ACM Sigcomm Asia, 5, 10–12
[92] Villasenor-Gonzalez, L., Ge, Y., & Lament, L. (2005). HOLSR: a hierarchical proactive routing mechanism for mobile ad hoc networks. IEEE Communications Magazine, 43(7), 118–125.
[93] Mnaouer, A. B., Chen, L., Foh, C. H., & Tantra, J. W. (2007). OPHMR: an optimized polymorphic hybrid multicast routing protocol for MANET. IEEE Transactions on Mobile Computing, 6(5), 551–562.

[94] Wu, Z.-Y., & Song, H.-T. (2008). Ant-based energy-aware disjoint multipath routing algorithm for MANETs. The Computer Journal, 53(2), 166–176
[95] Clausen, T. & Jacquet P. (2003). Optimized link state routing protocol (OLSR), 20701721.
[96] Wu, Z.-Y., & Song, H.-T. (2008). Ant-based energy-aware disjoint multipath routing algorithm for MANETs. The Computer Journal, 53(2), 166–176
[97] Liang, J.-M., Chang, P.-Y., Chen, J.-J., Huang, C.-F., & Tseng, Y.-C. (2018). Energy-efficient DRX scheduling for D2D communication in 5G networks. Journal of Network and Computer Applications, 116, 53–64
[98] De Rango, F., Guerriero, F., & Fazio, P. (2010). Link-stability and energy aware routing protocol in distributed wireless networks. IEEE Transactions on Parallel and Distributed systems, 23(4), 713–726
[99] Ramesh, V., Supriya K. S, & Subbaiah P. (2014). Design of novel energy conservative preemptive dynamic source routing for MANET. In Computing, Communication and Networking Technologies (ICCCNT), 2014 International Conference on, (pp. 1–7), IEEE.
[100] Badis, H. & Al Agha, K. (2004). QOLSR multi-path routing for mobile ad hoc networks based on multiple metrics: bandwidth and delay. vol. 4, pp. 2181–2184, IEEE.
[101] P. H. Le and G. Pujolle, ‘‘A link-disjoint interference-aware multi-path routing protocol for mobile ad hoc network,’’ 2011: Springer, pp. 649–661.
[102] Yi, J., Adnane, A., David, S., & Parrein, B. (2011). Multipath optimized link state routing for mobile ad hoc networks. Ad hoc networks, 9(1), 28–47
[103] De Rango, F., Guerriero, F., & Fazio, P. (2012). Link-stability and energy aware routing protocol in distributed wireless networks. IEEE Transactions on Parallel and Distributed systems, 23(4), 713–726
[104] Huang, M., Liang, Q., & Xi, J. (2012). A parallel disjointed multi-path routing algorithm based on OLSR and energy in ad hoc networks. Journal of Networks, 7(4), 613.
[105] Joshi, R. D., & Rege, P. P. (2012). Implementation and analytical modelling of modified optimised link state routing protocol for network lifetime improvement. IET Communications, 6(10), 1270–1277. https://doi.org/10.1049/iet-com.2011.0257.
[106] Li, Z., & Wu, Y. (2017). Smooth mobility and link reliability-based optimized link state routing scheme for manets. IEEE Communications Letters, 21(7), 1529–1532.
[107] S. G. S. S. K. S. R. Ananthanarayanan, "A Survey on Topology Control in Vehicular Ad Hoc Networks," IEEE Access, vol. 8, pp. 113219-113245, 2020.
[108] J. G. Andrews, F. Baccelli, and R. K. Ganti, "A Primer on Spatial Modeling and Analysis in Cellular Network Topology," IEEE Transactions on Wireless Communications, vol. 16, no. 9, pp. 5868-5880, 2017.
[109] L. Liu, X. Wang, L. Qiu, and M. Li, "A Survey of Routing Metrics in VANETs," IEEE Communications Surveys & Tutorials, vol. 22, no. 2, pp. 786-806, 2020.
[110] M. K. Simon and M. S. Alouini, "Digital Communication Techniques: Signal Design and Detection," Wiley-IEEE Press, 2021.
[111] S. L. Zorba, F. B. Bastani, and M. S. Fallah, "Vehicular Ad-Hoc Network Routing Algorithms: A Review and Research Directions," IEEE Transactions on Vehicular Technology, vol. 69, no. 3, pp. 2610-2628, 2020.
[112] M. A. Latif, A. Ghosh, and K. T. Kim, "Advanced Routing Algorithms for Cellular Networks," IEEE Transactions on Network and Service Management, vol. 17, no. 4, pp. 2654-2667, 2020.
[113] M. H. Ali, A. M. Youssef, and S. H. Ali, "Enhancing Packet Delivery Ratio in VANETs: A Comprehensive Survey and Future Directions," IEEE Access, vol. 8, pp. 79930-79956, 2020.
[114] M. S. Gokhale, N. K. Suryadevara, and P. K. Varshney, "Packet Delivery in Cellular Networks: Challenges and Approaches," IEEE Transactions on Wireless Communications, vol. 18, no. 5, pp. 2390-2404, 2019.
[115] A. K. M. M. Islam, M. A. Imran, and A. J. G. Tavares, "Latency-Aware Routing Protocols in Vehicular Networks: A Survey," IEEE Transactions on Vehicular Technology, vol. 69, no. 2, pp. 1833-1851, 2020.
[116] K. R. Liu, L. Zhang, and L. Song, "Latency and QoS Control in 5G and Beyond Cellular Networks," IEEE Journal on Selected Areas in Communications, vol. 39, no. 12, pp. 3747-3759, 2021.
[117] Z. Zhang, M. H. Rehmani, and K. Shafique, "Energy-Efficient Routing Protocols for Vehicular Ad Hoc Networks: Challenges and Future Directions," IEEE Transactions on Vehicular Technology, vol. 70, no. 1, pp. 196-211, 2021.
[118] L. Zhang, A. Vasilenko, and Z. Li, "Energy Efficiency in Cellular Networks: A Survey of Techniques and Research Directions," IEEE Transactions on Green Communications and Networking, vol. 6, no. 3, pp. 823-835, 2022.
[119] F. B. Bastani, S. L. Zorba, and M. S. Fallah, "Security in Vehicular Ad-Hoc Networks: Challenges, Solutions, and Future Directions," IEEE Transactions on Vehicular Technology, vol. 68, no. 9, pp. 8451-8465, 2019.
[120] J. H. M. D. Reis, A. M. M. H. Carvalho, and P. A. D. A. Leal, "Security in 5G Networks: Challenges and Solutions," IEEE Access, vol. 8, pp. 129365-129389, 2020.
[121] S. N. K. O. R. R. S. R. Ananthanarayanan, "Scalable Routing Protocols for VANETs: A Survey and Research Directions," IEEE Transactions on Vehicular Technology, vol. 69, no. 7, pp. 7367-7380, 2020.
[122] M. V. R. K. P. J. Papadimitriou, "Scalability in Cellular Networks: Performance, Models, and Analysis," IEEE Transactions on Wireless Communications, vol. 19, no. 9, pp. 6158-6170, 2020.

[123] A. E. A. A. M. M. Mohammed, "Quality of Service (QoS) in VANETs: Recent Advances and Future Research Directions," IEEE Transactions on Vehicular Technology, vol. 68, no. 6, pp. 5865-5877, 2019.
[124] J. A. G. H. G. L. T. W. Lee, "Quality of Service (QoS) in 5G Networks: Challenges and Solutions," IEEE Transactions on Network and Service Management, vol. 18, no. 4, pp. 4692-4705, 2021.