Routing Strategies and Protocols for Efficient Data Transmission in the Internet of Vehicles: A Comprehensive Review

Yijun Xu*
School of Automotive and Rail Transit, Nanjing Institute of Technology
Nanjing, Jiangsu 211167, China

***Abstract*—The Internet of Vehicles (IoV) integrates wireless communication, vehicular technology, and the Internet to create intelligent transportation systems. Efficient routing of data packets within the IoV is crucial for seamless communication and service enablement. This paper provides a comprehensive review of routing strategies and protocols in the IoV environment, categorizing and evaluating existing approaches. Routing protocols are classified, their adaptability is assessed to network variations, and their performance is compared. Insights are drawn from researchers' experiences. The paper offers a taxonomy of routing protocols, highlights adaptability to network conditions, and presents a comparative analysis. Lessons from researchers shed light on practical implications. The review identifies key routing challenges in IoV and provides a valuable resource for understanding and addressing these challenges in future research.**

***Keywords*—Internet of things; internet of vehicles; Vehicular Ad Hoc Networks (VANETs); routing; network adaptability; vehicular technology**

I. Introduction

The increasing number of users has led to a significant expansion of transportation systems in many countries [1]. However, these systems often suffer from inefficiency and high maintenance costs [2]. The global number of vehicles, including commercial and passenger vehicles, has slightly exceeded one billion, according to recent studies. Projections suggest that it will reach approximately two billion by 2035 [3]. In order to address these challenges, the development of Intelligent Transportation Systems (ITSs) aims to enhance traffic monitoring, road safety, and passenger comfort, ultimately reducing accidents [4]. Vehicular Ad hoc Networks (VANETs) are crucial in implementing intelligent transportation systems. VANETs enable real-time traffic information exchange between two modes of communication: Vehicle-to-Roadside (V2R) and Vehicle-to-Vehicle (V2V) [5]. By facilitating the transmission of warning messages and alerts, VANETs assist drivers in navigating through potential hazards [6]. The main goal of VANETs is to reduce travel time, cost, and pollutant emissions, which in turn enhances traffic safety and efficiency [7]. However, despite the potential benefits, modern vehicular networks face several challenges that must be addressed. Challenges are comprised of unstable internet service, personal devices' limited compatibility, commercialization restrictions, constrained processing capability, network architecture limitations, and no cloud computing services [8]. Addressing these issues is crucial to harness the full potential of VANETs and to ensure the successful deployment of advanced vehicular networks. By overcoming these challenges, the development of intelligent transportation systems can significantly improve the efficiency, reliability, and overall performance of transportation systems worldwide [9].

Data transmission in the IoV is a critical aspect of modern transportation systems, relying on several innovative technologies to optimize operations and enhance efficiency. Smart grids play a fundamental role by intelligently managing the distribution of energy, enabling Electric Vehicles (EVs) to be a part of IoV seamlessly [10]. Machine learning and deep learning algorithms analyze vast amounts of data generated by vehicles, traffic signals, and urban infrastructure. They derive valuable insights, predicting traffic patterns, suggesting optimal routes, and facilitating efficient energy usage, thereby significantly improving IoV's functionality [11-13]. Artificial Intelligence (AI) acts as the backbone, integrating these technologies and enabling decision-making processes in real time. It enables automated responses to traffic conditions, mitigating congestion and enhancing safety [14-16]. Association rule mining, on the other hand, extracts hidden patterns and correlations from diverse data sources within IoV, revealing valuable information about vehicle behavior, urban mobility, and energy consumption patterns. This knowledge is vital for optimizing routes, managing energy resources, and improving overall transportation efficiency [17]. Urban public transportation is a vital component of IoV, providing sustainable, shared mobility options. Integrating IoV technologies into public transportation enhances services by predicting demand, optimizing schedules, and ensuring a smoother passenger experience. This synergy is paramount in addressing urban traffic challenges, reducing emissions, and transitioning towards smarter, sustainable cities [18].

The IoV network consists of distributed nodes, including vehicles, roadside units, and sensors, which enable local communication. This distributed system facilitates edge computing and the interaction between communication and computation [19]. Artificial Intelligence (AI) is crucial in accessing the IoV network. The IoV network collects information from roadside units and mobile applications, utilizing the bandwidth of the 5G mobile network to enhance internet communication [20]. IoV finds applications in traffic management systems and industrial settings. The future of IoV research lies in leveraging big data algorithms to process data from IoT devices. It is an evolving field that attracts researchers' attention due to its relevance to human life. Routing protocols specific to the IoV environment are utilized, with SL-ZRP (Stable-Link State Zone Routing Protocol) being a significant communication protocol [21]. SL-ZRP is a function-based protocol that considers factors like speed, destination, and delay to determine optimal routes among vehicles, reducing network representation and overhead. The increasing number of road vehicles poses challenges such as accidents and associated expenses. IoV, originating from VANET, has been the subject of research for several years, addressing these issues. As people's lifestyles change, diverse requirements for vehicular networking have emerged, expanding the scale, structure, and applications of VANET. Large-scale and heterogeneous networks have been introduced, enabling services beyond safety information, including entertainment and environmental protection [22]. This paper proposes a routing protocol taxonomy and explores various IoV applications. This paper makes several significant contributions to the field of IoV:

- Classification of routing protocols: The paper provides a comprehensive classification of routing protocols specifically designed for the extreme and complex urban environment of IoV. This classification helps understand the different approaches and strategies employed by these protocols.
- Adaptability to network density and throughput variation: The paper recognizes the need for routing algorithms in IoV that can effectively handle low and high network densities while accommodating variations in throughput and delay. This highlights the importance of robust and adaptable routing solutions for the dynamic nature of vehicular networks.
- Comparison of routing protocols: The paper offers a comparative analysis of the various protocols in terms of their performance, scalability, reliability, and efficiency. This comparison assists in identifying the strengths and weaknesses of different protocols and aids in selecting the most suitable one for specific IoV scenarios.
- Lessons learned from researchers: The paper presents insights and lessons learned from researchers who have explored different challenges related to routing in IoV. This provides a deeper understanding of the practical implications and potential solutions for addressing the unique challenges faced in vehicular networks.

II. Background

A. Internet of Vehicle

The Internet of Things (IoT) is an evolving technology that links the digital and physical worlds, allowing for communication between objects and humans [23]. This concept has revolutionized our daily lives, making communication more informative, processing more intelligent, and devices smarter [24]. With IoT, the vision of seamless and ubiquitous communication, anytime and anywhere, is becoming a reality. IoT represents a significant transformation in our lifetime, following the universal accessibility of mobile devices and the world wide web [25]. IoT relies on key technologies such as short-range wireless communications, real-time localization, RFID, and sensor networks. These technologies enable various applications and research areas to flourish, particularly in smart transportation, smart industry, smart homes, and smart healthcare [26]. Integrating smartness in these areas has enhanced efficiency, convenience, and sustainability. Fig. 1 visually illustrates the diverse areas impacted by IoT, highlighting the interconnectedness of smart transportation, smart industry, smart homes, and smart healthcare. The widespread adoption of IoT transforms our environment into a smarter and more interconnected world, revolutionizing how we interact with objects and improving various aspects of our daily lives [27].The Internet of Vehicles (IoV) is a concept that combines VANET and IoT technologies to establish connections between various devices within vehicles and smart infrastructure on roads [28]. This integration enables seamless communication and data exchange among these devices, leading to a comprehensive IoV-based system [29]. This system includes embedded processors, onboard units, vehicles, roadside units, fog and edge devices, and cloud servers [30]. In an IoV-based system, devices can sense and collect various types of data, such as environmental and traffic-related data. The collected data is then shared among the devices, allowing collaboration and information exchange [31].

Additionally, the data collected from IoV devices can be combined with other data sources, such as social media data, user-generated data, and open-source intelligence, to provide valuable insights for decision-making at different levels [32]. One practical application of IoV-based systems is providing real-time traffic-related information to residents. The system can generate and disseminate up-to-date traffic information by utilizing the data collected from vehicles and roadside units, helping individuals make informed decisions about their routes and travel plans [33].

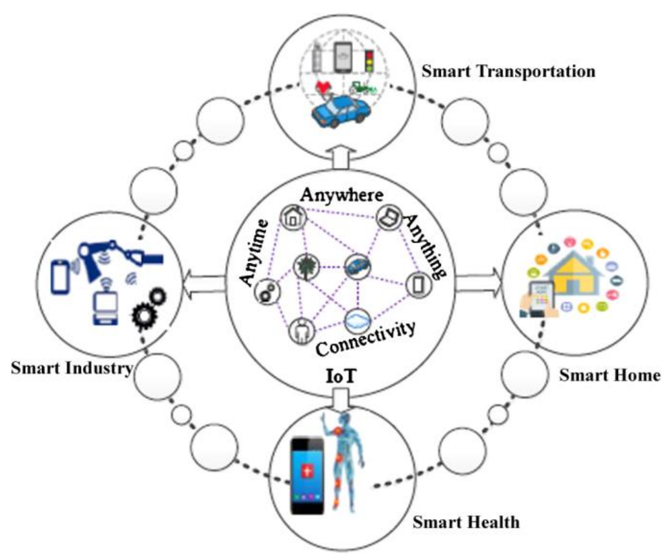

Fig. 1. Diverse areas impacted by IoT.

The IoV is increasingly implemented in urban areas to provide network access to drivers, people, and traffic management personnel. As the transportation system expands, it becomes more challenging and costly to maintain [34]. According to recent reports, the usage of IoV is widespread globally, and it is projected to have over three billion users by 2030. The increased number of vehicles has resulted in traffic congestion and a higher incidence of accidents [35]. To address these issues, IoV is being utilized in urban areas to improve traffic safety. Routing is a crucial aspect of IoV and is vital in daily life. It involves selecting the most optimal path for traffic networks or across multiple networks, considering the dynamic changes in topology [36]. IoV systems detect shortcomings and analyze data to make informed decisions for driving vehicles. Intelligent devices equipped with embedded processors and wireless technologies are utilized in IoV to facilitate vehicle communication [37]. By leveraging various forms of communication, such as device-to-device and machine-to-machine, IoV environments aim to enhance traffic safety in urban areas. Integrating IoV in urban settings aims to reduce traffic accidents by leveraging intelligent technologies and efficient communication. Through real-time data analysis and decision-making processes, IoV systems contribute to improving overall transportation efficiency and enhancing road safety [38].

Incorporating advanced communication and information technology, IoV brings several advantages in resolving traffic and driving challenges, leading to increased passenger safety and a superior driving experience. The communication components of IoV can be categorized into three main types: vehicular mobile Internet, inter-vehicular communication, and intra-vehicular communication [39]. As a heterogeneous vehicular network, IoV involves communication across five different types: Vehicle-to-Infrastructure (V2I), Vehicle-to-Sensors (V2S), Vehicle-to-Personal devices (V2P), Vehicle-to-Vehicle (V2V), and V2R, as illustrated in Fig. 2 [40]. To facilitate efficient communication in IoV, various wireless technologies are employed. These include vehicular communications such as Dedicated Short-Range Communications (DSRC) and Cellular Automata for Local Mobility (CALM), cellular mobile communication technologies like 4G/LTE, WiMax, and Satellite communication, as well as short-range static communication technologies like Zigbee, Bluetooth, and Wi-Fi [41]. The classification of these wireless communication technologies for IoV applications is depicted in Fig. 3. Fig. 4 provides a general overview of the structure of IoV, illustrating the interconnectedness and communication flow among vehicles, roadside units, sensors, and other components of the IoV ecosystem. This structure forms the foundation for efficiently exchanging information and data within the IoV network.

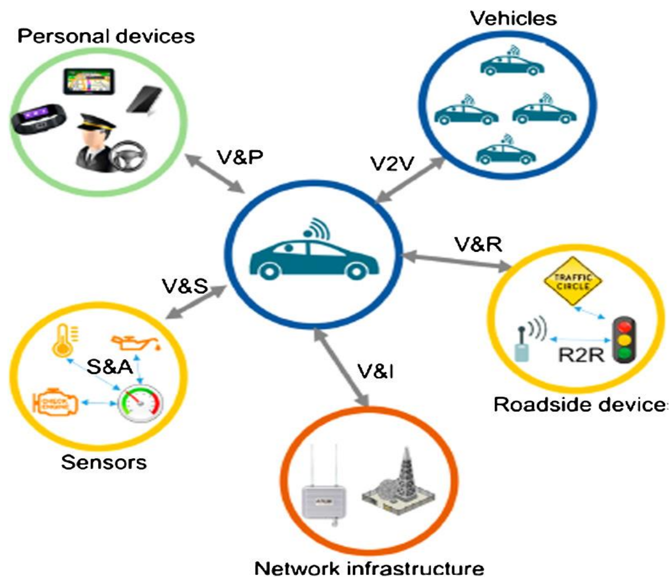

Fig. 2. Communications in IoV.

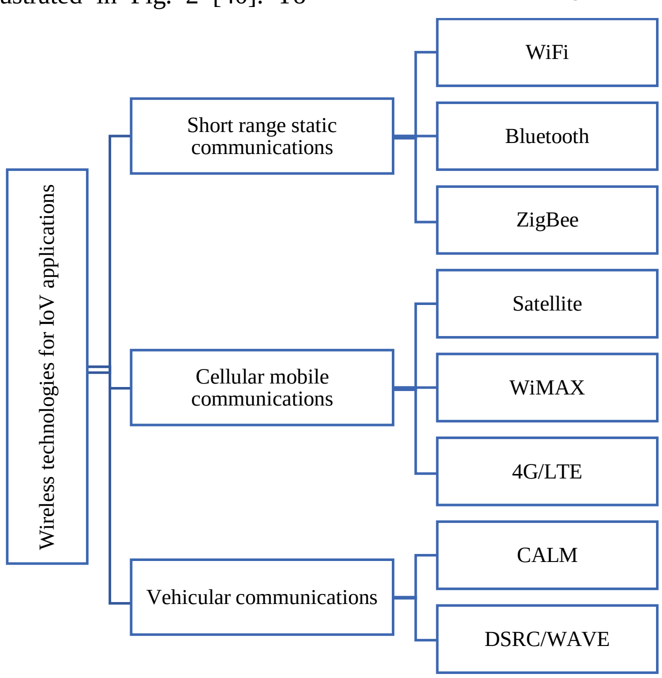

Fig. 3. Wireless communication technologies for IoV applications.

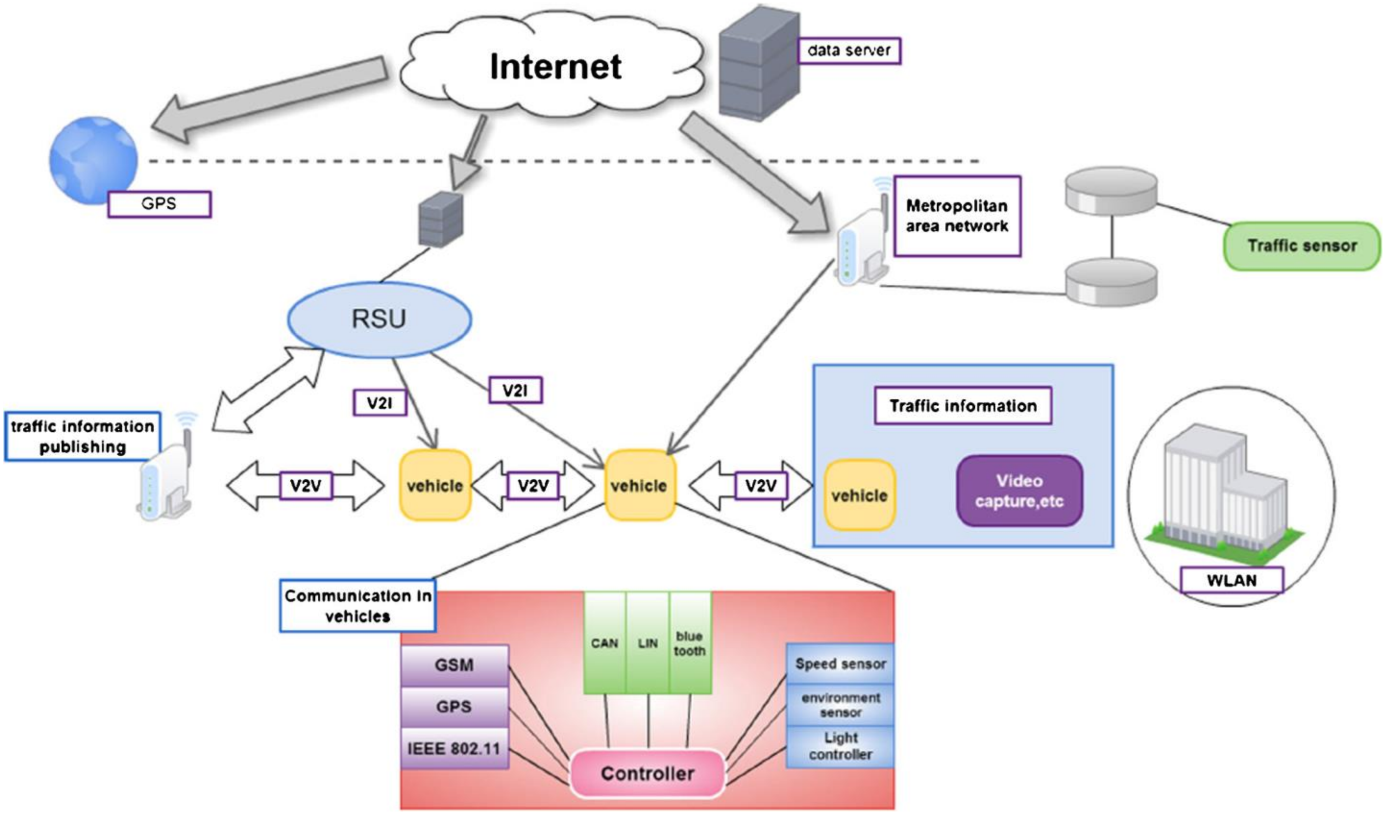

Fig. 4. A general overview of IoV.

The architecture of IoV is structured into four layers: the environment sensing and control layer, application layer, network access and transport layer, and coordinative computing control layer.

- Environment sensing and control layer: This layer plays a crucial role in implementing IoV services by focusing on vehicle control and the traffic environment. It involves sensing and gathering information from the vehicle's perspective and the surrounding environment. Vehicles utilize sensing technology to collect data about the environment, humans, and other vehicles to prevent accidents. Swarm sensing techniques gather dynamic information about the environment and facilitate cooperative decision-making.

- Network access and transport layer: Node management, data processing, remote monitoring, and data analysis are the main tasks in this layer. The IoV network provides every vehicle with diverse network access while taking into account network load constraints. The layer ensures efficient data transmission and handles the transportation of information between vehicles and infrastructure.

- Coordinative computing layer: This layer focuses on coordination within the IoV environment. It supports the interaction of cognitive computing capabilities and swarm intelligent coordinative computing capabilities. The coordinative computing layer facilitates data processing, resource allocation, and decision-making processes within the IoV system.

- Application layer: The application layer offers two types of services: closed and open services. Closed services are specific applications like control platforms and traffic command systems. Open services, provided by numerous internet service providers, include real-time traffic services and must support a suitable business model. Additionally, the application layer enables third-party providers to access open service capabilities, expanding the range of services available within the IoV ecosystem.

B. *IoV vs. VANET*

IoV, an advanced concept that combines VANETs and IoT, aims to enhance the capabilities of VANETs and strengthen ITS. While IoV and VANET technologies aim to improve driving experiences and reduce accidents, several parameters differentiate the two networks. These parameters include their goals, communication types, compatibility, range of usage, processing competence, market attention, network specifications, availability of internet facilities, data size, network connectivity, decision-making processes, the utility of applications, and network awareness [42]. VANETs primarily aim to enhance traffic safety and reduce travel time, costs, and pollutant emissions. However, it lacks entertainment features for passengers, leading to commercialization challenges [43].

On the other hand, IoV technology has broader goals, including improving traffic safety and efficiency and offering commercial infotainment services. IoV's entertainment provides passengers access to online video streaming, movies, file downloading, and other services, thus enhancing their overall experience. VANETs support two types of communication: V2I and V2V communication [44].

In contrast, IoV enables five types of communication: V2V, V2R, V2I, V2S, and V2P. Each communication type relies on different wireless technologies to exchange information. While individuals widely use personal devices like smartphones, laptops, and tablets, they face compatibility issues within VANETs due to incompatible network architectures [45]. As a result, personal devices cannot effectively communicate information with other nodes in VANETs. In contrast, IoV addresses this compatibility issue, enabling personal devices to efficiently disseminate information among other nodes in the event of hazards, fostering an interactive environment.

The range of usage in VANETs is limited to local and discrete applications, such as providing alerts to drivers about road incidents or avoiding collisions. The nodes in VANETs, which are vehicles, are temporary, random, and unstable, leading to lower scalability compared to IoV [46]. In contrast, IoV offers a global scope and sustainable applications/services by incorporating intelligent vehicular networks with computing and communication capabilities [47]. This enables intelligent networking among vehicles on a larger scale. VANETs face resource constraints regarding computation and processing capacity, as they primarily handle local information collected by sensors in the surrounding environment [48].

In contrast, IoV can handle global information, including big data [49]. Processing and analyzing data in real-time without any delays is crucial. Intelligent computing platforms like cloud computing, fog computing, and edge computing are utilized in IoV for efficient big data analytics and faster processing. VANETs have not achieved the desired commercialization over the years for various reasons, including unreliable internet connectivity, incompatibility with personal devices, and limitations in local processing capabilities. As a result, VANETs have not received significant market attention, and their usage has stagnated. On the other hand, IoV has experienced substantial research advancements and commercial interest. It benefits from reliable internet connectivity, compatibility with personal devices, and the rapid evolution of communication and computation technologies.

VANETs have a singleton network architecture, which limits their usage by not collaborating with other existing networks [50]. This lack of collaboration restricts their connectivity and functionality. In contrast, IoV utilizes a heterogeneous vehicular network framework that enables collaborative networking [51]. IoV incorporates five different types of communications, including WAVE, Wi-Fi, 4G/LTE, and satellite networks, which enhance the flexibility and connectivity of the architecture. Internet connectivity is a fundamental requirement in modern production environments. VANETs face challenges in extending internet connectivity, as roadside infrastructure may be scarce or not fully networked in certain areas.

On the other hand, IoV enables vehicles to connect to the Internet at any time, providing Internet services to all nodes. Faster and reliable internet services in IoV facilitate the implementation of an IoV environment with low latency, high reliability, and increased bandwidth. In terms of data, VANETs rely on limited local information for decision-making and lack collaboration with global data sources. In contrast, IoV is built on big data principles, as it generates a vast amount of real-time data regarding vehicle information. Additionally, the collaboration among various heterogeneous networks in IoV contributes to accumulating diverse data sources.

Vehicles in VANETs experience frequent disconnections from the ad-hoc network, resulting in a loss of network services. This is primarily due to the non-collaboration with other reachable networks and the pure ad-hoc network architecture. In contrast, vehicles in IoV remain connected to the best available network at all times, enabling efficient communication. IoV can easily collaborate with other reachable networks in case of any issues with the current network. In VANETs, the architecture imposes limitations on storage and computing, making it challenging to make intelligent decisions based on big data mining computations.

On the other hand, IoV architectures leverage Artificial Intelligence-based big data and data mining computations for decision-making. Due to the network disconnection issue in VANETs, the availability of ITS (Intelligent Transportation Systems) applications cannot be guaranteed. In IoV, ITS services are reliable and efficient due to using a client-server architecture with internet connectivity. In VANETs, network services and applications, such as safety messages, require exchanging event location and vehicle information. However, network awareness is limited to neighborhood awareness, as obstacles hinder the proper exchange of information. Additionally, vehicle processing and storage constraints contribute to reduced network awareness. In IoV, incorporating big data technologies like cloud computing and fog computing enhances the network's performance, allowing global network awareness.

III. Classification of IoV routing protocols

The routing protocols in IoV pose a significant challenge. While many routing protocols, such as DSDV, DSR, and AODV, are adapted from MANET, this article discusses specific geographical routing protocols like GPSR and GPCR. These routing protocols are classified based on their transmission strategies. Location-based routing protocols in IoV can be categorized into four types: hierarchical, geographic, broadcast, and geocast. Among these, geographical protocols are divided into unicast, broadcast, and geocast. The transmission strategy adopted classifies the routing protocols into unicast, geocast, and broadcast categories.

A. *Transmission Strategy*

The transmission strategy in routing protocols for IoV can be classified into three types: unicast routing protocol, geocast routing protocol, and broadcast routing protocol. Unicast routing protocol aims to transmit data from a single source to a single destination using a multi-hop technique through greedy forwarding. Intermediate vehicles can relay the data along a specific routing path from the source to the destination. The routing algorithm determines the forwarding decisions based on specific routing protocol characteristics. Unicast routing protocols can be further categorized based on the information they use into four types: topology-based, position-based, map-based, and path-based routing protocols. Fig. 5 illustrates the routing strategy and different routing protocols in IoV. The primary objective of geocast routing protocol is to transmit data from a single source node to all destination nodes within a specific geographical region called the Zone of Relevance. It employs a multicast service known as location-based multicast routing. Geocast routing is particularly useful for many VANET applications. Vehicles in the network receive and drop packets based on their current location. Traffic lights can help implement geocast routing. The broadcast routing protocol is commonly used for sharing information, such as traffic updates, weather emergencies, road conditions, advertisements, and announcements among vehicles. It is also used with unicast routing protocols to discover routes to destinations. Dissemination protocol for heterogeneous vehicular cooperative networks (DHVN) is an example of a broadcast routing protocol. Broadcast routing protocols rely on road topology and network connectivity to function effectively.

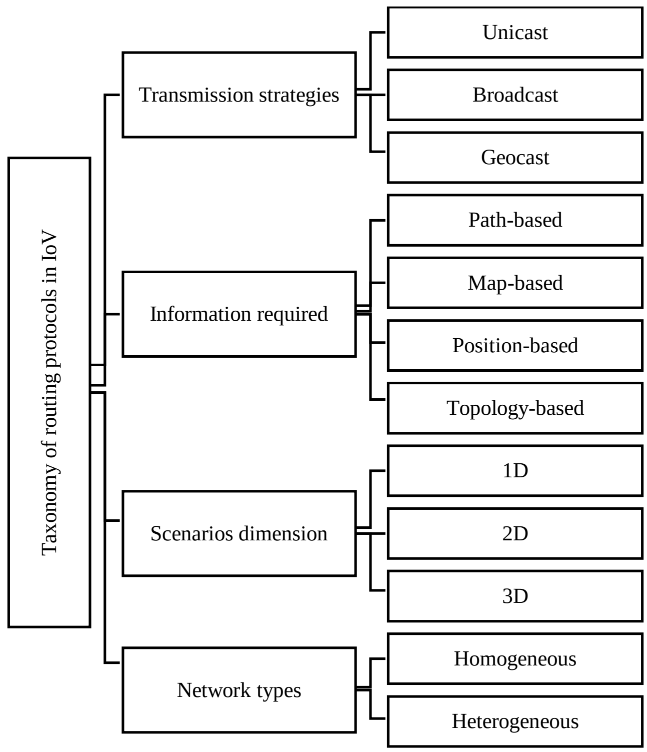

Fig. 5. Taxonomy of routing protocols in IoV.

B. Information Required

Based on the information required, routing protocols in IoV can be classified into four types:

Topology-based Routing: Topology-based routing protocols utilize information about the network's underlying structure, such as the connectivity and topology of the vehicles or infrastructure nodes. These protocols make routing decisions based on the network's topology, including the links between nodes and their quality metrics. Examples of topology-based routing protocols include DSDV (Destination-Sequenced Distance Vector) and OLSR (Optimized Link State Routing). Position-based routing protocols rely on the location information of the vehicles or nodes to make routing decisions. Each vehicle determines its position using GPS or other localization techniques and includes this information in the routing process. Protocols like GPSR (Greedy Perimeter Stateless Routing) and GPCR (Geographic Position-based Routing) fall into the category of position-based routing.

Map-based routing protocols utilize detailed road network maps to make routing decisions. These protocols consider the geographical layout and attributes of the road network, such as road segments, intersections, and traffic conditions. Map data is used to determine the optimal path for data transmission. Map-based routing protocols are commonly used in navigation and route planning applications. Path-based routing protocols focus on identifying specific paths or routes for data transmission. These protocols use predefined paths or routes, which can be determined based on factors like road conditions, traffic patterns, or specific requirements of the application. Path-based routing allows for more controlled and predetermined data routing. Examples of path-based routing protocols include AODV (Ad hoc On-Demand Distance Vector) and DSR (Dynamic Source Routing).

C. Scenarios Routing

In addition to the mentioned protocols, there are several other routing protocols in the context of IoV, namely, vehicular routing protocol, Delay Tolerant Routing Protocol (DTN), and Disrupted Adaptive Routing (DAR). Table I shows the classification of IOV routing protocols. Vehicular routing protocol focuses on exchanging road information among vehicles to enable efficient routing. It utilizes techniques like ant colony optimization, where vehicles act as ants to find the optimal path based on local information and pheromone trails left by other vehicles. DTN is designed to handle intermittent or disrupted connectivity in the network. It employs a carryforward mechanism, where intermediate nodes store and forward data until a suitable connection becomes available for transmission. DAR is a routing protocol that aims to reduce network congestion and improve overall performance compared to traditional routing protocols. It achieves this by dynamically adapting the routing paths based on network conditions, thereby reducing transmission delays and improving packet delivery.

In IoV networks, routing scenarios are divided into three types: 1D, 2D, and 3D. 1D scenarios involve vehicles moving in a linear direction, such as on a highway or a single-lane road. Routing protocols are designed to facilitate efficient data transmission along this one-dimensional path. In 2D scenarios, vehicles can move in a two-dimensional space, such as urban or suburban areas with multiple lanes and intersections. Routing protocols consider the spatial relationships and connectivity between vehicles in these environments. 3D scenarios involve routing in complex environments where vehicles can move in three dimensions, such as in aerial or underwater vehicular networks. Routing protocols in these scenarios need to account for the specific challenges and characteristics of the respective environments.

D. Network Types

Routing is feasible in both homogeneous and heterogeneous networks within the IoV framework. In a homogeneous network, vehicles and network elements have comparable characteristics and capabilities. The routing protocols for homogeneous networks assume that vehicles have similar communication ranges, transmission capabilities, and network behaviors. Examples of homogeneous networks in IoV include all vehicles equipped with the same communication technology (e.g., all vehicles use Wi-Fi or DSRC for communication). In a heterogeneous network, vehicles and network elements may have different characteristics, capabilities, and communication technologies. Heterogeneous networks in IoV may involve vehicles with different communication ranges, transmission powers, and technologies (e.g., a mix of vehicles using Wi-Fi, cellular networks, or satellite communication). Routing protocols for heterogeneous networks must consider these differences and ensure effective communication and data exchange among vehicles with diverse capabilities.

Routing protocols in homogeneous and heterogeneous networks aim to find the most efficient paths for data transmission, considering factors like network congestion, connectivity, data reliability, and quality of service requirements. The specific design and implementation of routing protocols may vary depending on the characteristics and objectives of the network. Still, the overall goal remains the same: to establish reliable and optimal routes for data transmission in IoV networks.

TABLE I. CLASSIFICATION OF IOV ROUTING PROTOCOLS

Routing protocol type	Information required	Scenarios routing	Network types	Strengths	Examples
Unicast routing	Topology-based	1D and 2D	Homogeneous	Reliable point-to-point communication	DSDV and AODV
	Position-based	1D and 2D	Homogeneous	Efficient use of position information	DSDV and AODV
	Map-based	1D and 2D	Homogeneous	Utilizes detailed road network maps	DSDV and AODV
	Path-based	1D and 2D	Homogeneous	Offers predetermined data routing	DSDV and AODV
Geocast routing	Position-based	2D	Heterogeneous	Efficient data transmission within a specific geographical region	GPSR and GPCR
Broadcast routing	Topology-based	1D and 2D	Homogeneous	Effective for sharing information among vehicles	DHVN
	Map-based	1D and 2D	Homogeneous	Utilizes road network attributes	DHVN
	Path-based	1D and 2D	Homogeneous	Provides controlled data routing	DHVN
Vehicular Routing	Various	Various	Various	Utilizes intelligent algorithms like ant colony optimization	Ant Colony, DTN, and DAR

IV. DISCUSSION

In this section, we provide a detailed discussion of the findings and insights gained from the classification of IoV routing protocols. Our comprehensive classification of IoV routing protocols offers a structured approach to categorizing and understanding the diverse strategies employed in vehicular networks. By grouping protocols into three main categories based on their transmission strategies (unicast, geocast, and broadcast), we facilitate a clearer view of their roles and functionalities. This classification provides researchers and practitioners with a valuable roadmap for selecting the most suitable routing protocols for specific IoV scenarios. Unicast routing protocols offer reliable point-to-point communication within IoV networks. Their strengths lie in efficient position-based routing, the utilization of detailed road network maps, and the ability to provide predetermined data routing. These characteristics make them suitable for various IoV scenarios. Through multi-hop forwarding, intermediate vehicles can relay data, facilitating communication even when the destination is not in the direct transmission range of the source. Unicast protocols are adaptable and can be further categorized based on the information they use, such as topology-based, position-based, map-based, and path-based routing protocols. This flexibility allows for protocol selection that best suits the specific requirements of IoV scenarios. However, these protocols have their limitations. They may face challenges related to network congestion in scenarios with a high density of vehicles. Moreover, data reliability and latency can become concerns in scenarios with dynamic network conditions, necessitating the development of more robust routing algorithms.

Geocast routing protocols are specifically designed to transmit data from a single source to all destination nodes within a predefined geographical region known as the Zone of Relevance. Their strength lies in efficiently disseminating information to a targeted area, making them particularly useful for many vehicular applications. Geocast protocols leverage location-based multicast routing, where vehicles within the designated zone receive and process packets based on their current location. This approach ensures that only vehicles within the relevant geographical area receive the data, reducing unnecessary network traffic. However, geocast protocols have limitations concerning the definition and management of these geographical zones. The accuracy of defining such regions and handling scenarios with overlapping or rapidly changing zones can pose challenges.

Broadcast routing protocols play a crucial role in sharing real-time information among vehicles. Their strength lies in their ability to quickly disseminate critical updates, such as traffic conditions, weather emergencies, or road incidents, to a wide audience of vehicles. Broadcast protocols are often used in conjunction with unicast routing protocols to discover routes to destinations. However, they also have limitations. Broadcasting can lead to network congestion, especially in densely populated areas, where a large number of vehicles simultaneously receive and process broadcast messages. To mitigate this, efficient mechanisms for broadcast suppression and congestion control are necessary. Moreover, ensuring data reliability and minimizing redundant data reception are ongoing challenges in broadcast routing, as data packets may be received by vehicles multiple times.

Configuring routing protocols in the context of the IoV involves a range of parameters that influence how data is routed and communicated within the network. The choice of the routing algorithm is fundamental. IoV can employ various routing protocols, including proactive (table-driven) like OLSR or reactive (on-demand) like AODV. The selection depends on factors like network size, mobility, and application requirements. Parameters related to the network's physical layout, including the number of vehicles, their initial positions, and the road infrastructure, play a significant role. Realistic network topologies are essential for accurate simulations. The communication range of IoV devices, often determined by the technology used (e.g., DSRC, Wi-Fi, cellular), is crucial. It affects how far vehicles can communicate with each other and with roadside infrastructure. Some routing protocols allow for configuring transmission power levels. Adjusting transmission power affects the range at which a vehicle can communicate, influencing network coverage and energy consumption. Parameters related to packet generation, including packet size and transmission rate, can vary depending on the type of data being exchanged. Larger packets or higher transmission rates may require different routing strategies.

Different mobility models, such as Random Waypoint, Gauss-Markov, or real-world traffic data, can be used to simulate vehicle movements. The choice of mobility model affects how vehicles move and interact within the network. In wireless communication, propagation models define how signals propagate through the environment. These models consider factors like path loss, shadowing, and fading, impacting signal strength and reliability. Parameters related to traffic patterns, such as the type of data generated (e.g., safety messages, multimedia), traffic density, and source-destination pairs, are essential for evaluating routing performance. If the IoV application demands specific QoS, parameters related to latency, jitter, and reliability thresholds may be configured to ensure that routing decisions meet these requirements. Routing protocols in IoV often include security features. Parameters for encryption, authentication, and key management may need configuration to ensure secure communication. Factors like vehicle speed, acceleration, and braking characteristics can be modeled as parameters. These parameters influence how vehicles move and interact in the network. The length of the simulation or data collection period can impact the stability and convergence of routing protocols. Longer simulations may be needed to observe certain network behaviors.

V. Future Research Directions

- Standardization and interoperability: Standardization efforts are crucial to ensure widespread adoption and interoperability of routing algorithms in the IoV. Future research should focus on developing standardized routing protocols and interfaces that enable seamless communication across different vehicular networks and technologies.

- Blockchain-enabled routing: Blockchain technology offers decentralized, transparent, and tamper-resistant data management. Integrating blockchain into routing algorithms can enhance trust, security, and privacy in the IoV. Future research should explore the application of blockchain-enabled routing algorithms that can provide secure and reliable communication among vehicles and infrastructure.

- Machine learning-based routing: Machine learning techniques have shown promise in various domains. Applying machine learning algorithms to routing in the IoV can enable proactive decision-making, traffic prediction, and congestion control. Future research should investigate the use of machine learning-based routing algorithms that can adapt and learn from network dynamics to optimize routing decisions.

- Edge computing and intelligent routing: With the proliferation of edge computing in the IoV, there is an opportunity to leverage edge resources for intelligent routing. Future research should explore intelligent routing algorithms that can utilize edge computing capabilities, such as real-time data processing, decision-making, and resource optimization, to improve routing efficiency and responsiveness.

- Quality of Service (QoS): The IoV requires different communication services with varying QoS requirements. Routing algorithms should be able to provide differentiated services based on application-specific QoS metrics, such as latency, reliability, and throughput. Future research should investigate QoS-aware routing algorithms that can efficiently handle diverse application requirements.

- Security and privacy: Security and privacy are critical concerns in vehicular networks. Routing algorithms should incorporate robust security mechanisms to protect against attacks and ensure data confidentiality, integrity, and availability. Future research should focus on developing secure routing protocols and privacy-preserving techniques to mitigate threats and protect user privacy effectively.
- Resilience to attacks: Vehicular networks are susceptible to jamming, spoofing, and Sybil attacks. Routing algorithms should be resilient to such attacks and capable of detecting and mitigating them. Future research should explore routing algorithms that can enhance the network's resilience and ensure reliable communication in the presence of malicious entities.
- Scalability: As the number of connected vehicles increases, scalability becomes a major challenge. Designing routing algorithms that can efficiently handle large-scale networks is crucial. Future research should focus on developing scalable routing schemes that effectively handle increasing vehicles and data traffic.
- Dynamic network conditions: Vehicular networks are characterized by high mobility, intermittent connectivity, and dynamic network topologies. Routing algorithms must adapt to these conditions to ensure reliable and efficient communication. Future research should explore adaptive routing algorithms that dynamically adjust routing paths based on the current network state.
- Energy efficiency: Vehicles in the IoV are typically resource-constrained, especially in terms of energy. Routing algorithms should consider energy consumption and aim to minimize energy expenditure. Future research should focus on energy-aware routing algorithms that optimize energy consumption while maintaining reliable communication.
- Integration with smart city infrastructure: The IoV is closely linked to the concept of smart cities. Routing algorithms should be designed to integrate with existing smart city infrastructure, such as traffic management systems, intelligent transportation systems, and urban sensing networks. Future research should explore routing algorithms that can seamlessly integrate with smart city infrastructure to enable efficient and sustainable urban mobility.
- Traffic load balancing: In congested scenarios, routing algorithms should distribute traffic load evenly across the network to prevent congestion and ensure efficient resource utilization. Future research should focus on load-balancing routing algorithms that intelligently distribute traffic and optimize network performance.
- Vehicular cloud computing: Integrating cloud computing with vehicular networks offers opportunities for offloading computation and storage tasks to the cloud. Routing algorithms should consider the availability and utilization of cloud resources to optimize communication and resource allocation. Future research should explore routing algorithms that leverage vehicular cloud computing for enhanced scalability, resource management, and application performance.
- Cross-layer optimization: Traditional layered network architectures may not be suitable for the dynamic and resource-constrained IoV environment. To improve routing performance, cross-layer optimization techniques can leverage interactions between different layers (e.g., physical, MAC, and network). Future research should investigate cross-layer routing algorithms that optimize communication efficiency, reliability, and resource utilization.
- Robustness to mobility: Vehicles in the IoV are highly mobile, resulting in frequent topology changes and link disruptions. Routing algorithms should be robust to mobility-induced challenges and maintain connectivity even in highly dynamic environments. Future research should explore mobility-aware routing algorithms that can adapt to vehicle movements and ensure seamless communication.
- Cooperative communication and collaboration: Cooperative communication among vehicles and infrastructure can improve routing efficiency, reliability, and safety in the IoV. Research should focus on cooperative routing algorithms that enable vehicles to collaborate, exchange information, and assist each other in routing decisions, leading to enhanced network performance.
- Context-aware routing: The IoV is rich in contextual information, including vehicle positions, speeds, traffic conditions, and environmental factors. Incorporating context awareness into routing algorithms can optimize route selection based on the current context and improve overall network performance. Future research should explore context-aware routing algorithms that leverage contextual information for intelligent and adaptive routing decisions.
- Multi-hop communication: In the IoV, vehicles may need to rely on multi-hop communication to reach distant destinations or overcome connectivity gaps. Research should focus on developing efficient multi-hop routing algorithms that can optimize message forwarding and ensure reliable end-to-end communication.
- Heterogeneous network integration: The IoV encompasses various communication technologies, such as cellular networks, dedicated short-range communication (DSRC), and Wi-Fi. Integrating these heterogeneous networks poses challenges in terms of routing and seamless handover. Future research should explore routing algorithms that effectively integrate and manage heterogeneous networks to provide uninterrupted connectivity.

- Real-time traffic management: Routing algorithms in the IoV should consider real-time traffic information to make informed routing decisions. Future research should explore integrating real-time traffic data, such as congestion and traffic flow information, into routing algorithms to enable efficient traffic management and avoidance.

VI. Conclusion

The IoV is a transformative technology that enables autonomous driving scenarios by connecting people, intelligent vehicle systems, and cyber-physical systems in urban environments. It has attracted significant commercial and research attention due to advancements in computation and communication technologies, such as edge computing, grid computing, parallel processing, big data analysis, web semantics, and artificial intelligence. The IoV network employs protocols like position, map, and path-based to enable intelligent applications related to road conditions, vehicle preemption, and information services. Maintaining routes in the dynamic IoV network, particularly in homogeneous networks like VANETs, presents challenges due to mobile node behavior. To address this, the IoV network is categorized into 1D, 2D, and 3D scenarios, with Plane-based routing focusing on the latter. However, plane-based routing has limitations in real-world scenarios due to the absence of the third dimension. The IoV network is further divided into homogeneous and heterogeneous networks to optimize vehicle utilization, offering the potential for future development. The paper emphasizes the IoV network's layered architecture, communication, data analysis, and recent challenges, providing valuable insights for researchers and industries. It acknowledges including traditional VANETs and large-scale heterogeneous network structures within the IoV network.

This study has certain limitations that provide opportunities for future research. Firstly, our classification and analysis of IoV routing protocols are primarily based on a theoretical framework. While this provides a structured understanding of these protocols, practical evaluations through extensive simulations and real-world experiments are necessary to validate their performance under varying network conditions. Secondly, the study focuses on existing IoV routing protocols but does not explore the development of novel routing solutions tailored to emerging IoV challenges, such as autonomous vehicles, the integration of 5G, and the proliferation of IoT devices in urban environments. Future research could delve into the design and evaluation of innovative routing protocols that effectively address these evolving demands. Moreover, the security aspects of IoV routing, including privacy preservation and protection against cyberattacks, remain a critical concern. Investigating the integration of robust security measures into routing protocols is essential for ensuring the integrity and confidentiality of data in vehicular networks. Lastly, the study primarily addresses routing at the network layer, and future work could explore the interactions between routing protocols and higher-layer applications, such as traffic management and autonomous vehicle coordination. These areas represent promising avenues for enhancing the efficiency, safety, and overall performance of IoV networks.

Acknowledgment

This work was supported by the Natural Science Foundation of the Higher Education Institutions of Jiangsu Province (No.22KJD460005).

This work was supported by the Scientific Research Foundation of Nanjing Institute of Technology (No. YKJ201994).

References

[1] T. Palit, A. M. Bari, and C. L. Karmaker, "An integrated Principal Component Analysis and Interpretive Structural Modeling approach for electric vehicle adoption decisions in sustainable transportation systems," Decision Analytics Journal, vol. 4, p. 100119, 2022.

[2] A. Bhargava, D. Bhargava, P. N. Kumar, G. S. Sajja, and S. Ray, "Industrial IoT and AI implementation in vehicular logistics and supply chain management for vehicle mediated transportation systems," International Journal of System Assurance Engineering and Management, vol. 13, no. Suppl 1, pp. 673-680, 2022.

[3] C. Zhang et al., "Flexible grid-based electrolysis hydrogen production for fuel cell vehicles reduces costs and greenhouse gas emissions," Applied Energy, vol. 278, p. 115651, 2020.

[4] Y. Fu, C. Li, F. R. Yu, T. H. Luan, and Y. Zhang, "A survey of driving safety with sensing, vehicular communications, and artificial intelligence-based collision avoidance," IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 7, pp. 6142-6163, 2021.

[5] B. Pourghebleh and N. Jafari Navimipour, "Towards efficient data collection mechanisms in the vehicular ad hoc networks," International Journal of Communication Systems, vol. 32, no. 5, p. e3893, 2019.

[6] P. Shah and T. Kasbe, "A review on specification evaluation of broadcasting routing protocols in VANET," Computer Science Review, vol. 41, p. 100418, 2021.

[7] M. J. N. Mahi et al., "A review on VANET research: Perspective of recent emerging technologies," IEEE Access, 2022.

[8] Z. Yang, L. Li, F. Gu, and X. Ling, "Dependable and reliable cloud-based architectures for vehicular communications: A systematic literature review," International Journal of Communication Systems, vol. 36, no. 7, p. e5457, 2023.

[9] N. H. Hussein, C. T. Yaw, S. P. Koh, S. K. Tiong, and K. H. Chong, "A Comprehensive Survey on Vehicular Networking: Communications, Applications, Challenges, and Upcoming Research Directions," IEEE Access, vol. 10, pp. 86127-86180, 2022.

[10] J. Webber, A. Mehbodniya, A. Arafa, and A. Alwakeel, "Improved Human Activity Recognition Using Majority Combining of Reduced-Complexity Sensor Branch Classifiers," Electronics, vol. 11, no. 3, p. 392, 2022.

[11] C. Han and X. Fu, "Challenge and Opportunity: Deep Learning-Based Stock Price Prediction by Using Bi-Directional LSTM Model," Frontiers in Business, Economics and Management, vol. 8, no. 2, pp. 51-54, 2023.

[12] R. Soleimani and E. Lobaton, "Enhancing Inference on Physiological and Kinematic Periodic Signals via Phase-Based Interpretability and Multi-Task Learning," Information, vol. 13, no. 7, p. 326, 2022.

[13] S. N. H. Bukhari, J. Webber, and A. Mehbodniya, "Decision tree based ensemble machine learning model for the prediction of Zika virus T-cell epitopes as potential vaccine candidates," Scientific Reports, vol. 12, no. 1, p. 7810, 2022.

[14] B. M. Jafari, M. Zhao, and A. Jafari, "Rumi: An Intelligent Agent Enhancing Learning Management Systems Using Machine Learning Techniques," Journal of Software Engineering and Applications, vol. 15, no. 9, pp. 325-343, 2022.

[15] J. Webber, A. Mehbodniya, Y. Hou, K. Yano, and T. Kumagai, "Study on idle slot availability prediction for WLAN using a probabilistic neural network," in 2017 23rd Asia-Pacific Conference on Communications (APCC), 2017: IEEE, pp. 1-6.

[16] H. Kosarirad, M. Ghasempour Nejati, A. Saffari, M. Khishe, and M. Mohammadi, "Feature Selection and Training Multilayer Perceptron Neural Networks Using Grasshopper Optimization Algorithm for Design

Optimal Classifier of Big Data Sonar," Journal of Sensors, vol. 2022, 2022.

[17] M. Shahin et al., "Cluster-based association rule mining for an intersection accident dataset," in 2021 International Conference on Computing, Electronic and Electrical Engineering (ICE Cube), 2021: IEEE, pp. 1-6, doi: 10.1109/ICECube53880.2021.9628206.

[18] S. Saeidi, S. Enjedani, E. Alvandi Behineh, K. Tehranian, and S. Jazayerifar, "Factors Affecting Public Transportation Use during Pandemic: An Integrated Approach of Technology Acceptance Model and Theory of Planned Behavior," Tehnički glasnik, vol. 18, pp. 1-12, 09/01 2023, doi: 10.31803/tg-20230601145322.

[19] T. Kayarga and S. A. Kumar, "A study on various technologies to solve the routing problem in Internet of Vehicles (IoV)," Wireless Personal Communications, vol. 119, pp. 459-487, 2021.

[20] X. Xu, H. Li, W. Xu, Z. Liu, L. Yao, and F. Dai, "Artificial intelligence for edge service optimization in internet of vehicles: A survey," Tsinghua Science and Technology, vol. 27, no. 2, pp. 270-287, 2021.

[21] R. Gasmi, M. Aliouat, and H. Seba, "A stable link based zone routing protocol (SL-ZRP) for internet of vehicles environment," Wireless Personal Communications, vol. 112, pp. 1045-1060, 2020.

[22] B. Ji et al., "Survey on the internet of vehicles: Network architectures and applications," IEEE Communications Standards Magazine, vol. 4, no. 1, pp. 34-41, 2020.

[23] F. Kamalov, B. Pourghebleh, M. Gheisari, Y. Liu, and S. Moussa, "Internet of Medical Things Privacy and Security: Challenges, Solutions, and Future Trends from a New Perspective," Sustainability, vol. 15, no. 4, p. 3317, 2023.

[24] M. Mohseni, F. Amirghafouri, and B. Pourghebleh, "CEDAR: A cluster-based energy-aware data aggregation routing protocol in the internet of things using capuchin search algorithm and fuzzy logic," Peer-to-Peer Networking and Applications, pp. 1-21, 2022.

[25] B. Pourghebleh and N. J. Navimipour, "Data aggregation mechanisms in the Internet of things: A systematic review of the literature and recommendations for future research," Journal of Network and Computer Applications, vol. 97, pp. 23-34, 2017.

[26] B. Pourghebleh, V. Hayyolalam, and A. A. Anvigh, "Service discovery in the Internet of Things: review of current trends and research challenges," Wireless Networks, vol. 26, no. 7, pp. 5371-5391, 2020.

[27] B. Pourghebleh, N. Hekmati, Z. Davoudnia, and M. Sadeghi, "A roadmap towards energy-efficient data fusion methods in the Internet of Things," Concurrency and Computation: Practice and Experience, p. e6959, 2022.

[28] S. El Madani, S. Motahhir, and A. El Ghzizal, "Internet of vehicles: concept, process, security aspects and solutions," Multimedia Tools and Applications, vol. 81, no. 12, pp. 16563-16587, 2022.

[29] A. Hbaieb, S. Ayed, and L. Chaari, "A survey of trust management in the Internet of Vehicles," Computer Networks, vol. 203, p. 108558, 2022.

[30] N. K. Narang, "Mentor's Musings on the Role of Standards in Improving the Privacy, Trust and Reputation Management in Internet of Vehicles (IoV)," IEEE Internet of Things Magazine, vol. 6, no. 2, pp. 18-23, 2023.

[31] A. Salim, A. M. Khedr, B. Alwasel, W. Osamy, and A. Aziz, "SOMACA: A New Swarm Optimization-Based and Mobility-Aware Clustering Approach for the Internet of Vehicles," IEEE Access, 2023.

[32] A. Guerna, S. Bitam, and C. T. Calafate, "Roadside unit deployment in internet of vehicles systems: A survey," Sensors, vol. 22, no. 9, p. 3190, 2022.

[33] N. Azzaoui, A. Korichi, B. Brik, and H. Amirat, "A survey on data dissemination in internet of vehicles networks," Journal of Location Based Services, pp. 1-44, 2022.

[34] B. Ji et al., "A vision of IoV in 5G HetNets: architecture, key technologies, applications, challenges, and trends," IEEE Network, vol. 36, no. 2, pp. 153-161, 2022.

[35] B. P. Rimal, C. Kong, B. Poudel, Y. Wang, and P. Shahi, "Smart electric vehicle charging in the era of internet of vehicles, emerging trends, and open issues," Energies, vol. 15, no. 5, p. 1908, 2022.

[36] G. Husnain, S. Anwar, and F. Shahzad, "An Enhanced AI-Enabled Routing Optimization Algorithm for Internet of Vehicles (IoV)," Wireless Personal Communications, vol. 130, no. 4, pp. 2623-2643, 2023.

[37] R. Dhanare, K. K. Nagwanshi, and S. Varma, "A study to enhance the route optimization algorithm for the internet of vehicle," Wireless Communications and Mobile Computing, vol. 2022, 2022.

[38] N. M. Elfatih et al., "Internet of vehicle's resource management in 5G networks using AI technologies: Current status and trends," IET Communications, vol. 16, no. 5, pp. 400-420, 2022.

[39] S. J. Kamble and M. R. Kounte, "Enabling technologies for internet of vehicles," in Proceeding of the International Conference on Computer Networks, Big Data and IoT (ICCBI-2018), 2020: Springer, pp. 257-268.

[40] S. Sharma and B. Kaushik, "Applications and challenges in internet of vehicles: A survey," Internet of Things and Its Applications: Select Proceedings of ICIA 2020, pp. 55-65, 2022.

[41] S. Sharma and B. Kaushik, "A survey on nature-inspired algorithms and its applications in the Internet of Vehicles," International Journal of Communication Systems, vol. 34, no. 12, p. e4895, 2021.

[42] S. Kumar and J. Singh, "Internet of Vehicles over VANETs: smart and secure communication using IoT," Scalable Computing: Practice and Experience, vol. 21, no. 3, pp. 425-440, 2020.

[43] M. Lee and T. Atkison, "Vanet applications: Past, present, and future," Vehicular Communications, vol. 28, p. 100310, 2021.

[44] C. R. Storck and F. Duarte-Figueiredo, "A survey of 5G technology evolution, standards, and infrastructure associated with vehicle-to-everything communications by internet of vehicles," IEEE access, vol. 8, pp. 117593-117614, 2020.

[45] H. Vasudev, D. Das, and A. V. Vasilakos, "Secure message propagation protocols for IoVs communication components," Computers & Electrical Engineering, vol. 82, p. 106555, 2020.

[46] H. H. Jeong, Y. C. Shen, J. P. Jeong, and T. T. Oh, "A comprehensive survey on vehicular networking for safe and efficient driving in smart transportation: A focus on systems, protocols, and applications," Vehicular Communications, vol. 31, p. 100349, 2021.

[47] W. Xu, Y. Zhang, F. Wang, Z. Qin, C. Liu, and P. Zhang, "Semantic Communication for the Internet of Vehicles: A Multiuser Cooperative Approach," IEEE Vehicular Technology Magazine, 2023.

[48] E. Qafzezi, K. Bylykbashi, P. Ampririt, M. Ikeda, K. Matsuo, and L. Barolli, "An intelligent approach for cloud-fog-edge computing SDN-VANETs based on fuzzy logic: effect of different parameters on coordination and management of resources," Sensors, vol. 22, no. 3, p. 878, 2022.

[49] K. N. Qureshi, S. Din, G. Jeon, and F. Piccialli, "Internet of vehicles: Key technologies, network model, solutions and challenges with future aspects," IEEE Transactions on Intelligent Transportation Systems, vol. 22, no. 3, pp. 1777-1786, 2020.

[50] D. T. Le, K. Q. Dang, Q. L. T. Nguyen, S. Alhelaly, and A. Muthanna, "A behavior-based malware spreading model for vehicle-to-vehicle communications in VANET networks," Electronics, vol. 10, no. 19, p. 2403, 2021.

[51] A. M. Khasawneh et al., "Service-centric heterogeneous vehicular network modeling for connected traffic environments," Sensors, vol. 22, no. 3, p. 1247, 2022.