IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received April 4, 2022, accepted May 24, 2022, date of publication June 16, 2022, date of current version June 24, 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3183605

A Review on VANET Research: Perspective of Recent Emerging Technologies

MD. JULKAR NAYEEN MAHI[1], SUDIPTO CHAKI[2], SHAMIM AHMED[2], MILON BISWAS[2], (Member, IEEE), M. SHAMIM KAISER[3], (Senior Member, IEEE), MOHAMMAD SHAHIDUL ISLAM[3], MEHDI SOOKHAK[4], (Senior Member, IEEE), ALISTAIR BARROS[5], AND MD WHAIDUZZAMAN[1,3,5], (Senior Member, IEEE)

[1]Department of Software Engineering, Daffodil International University, Daffodil Smart City, Dhaka 1207, Bangladesh
[2]Department of Computer Science and Engineering, Bangladesh University of Business and Technology, Dhaka 1216, Bangladesh
[3]Institute of Information Technology, Jahangirnagar University, Dhaka 1342, Bangladesh
[4]School of Engineering and Computing Sciences, Texas A&M University, Corpus Christ, TX 78412, USA
[5]School of Information Systems, Queensland University of Technology, Brisbane, QLD 4000, Australia

Corresponding author: Md Whaiduzzaman (wzaman@juniv.edu)

This work was supported by the Australian Research Council Discovery Project under Grant DP190100314, "Re-Engineering Enterprise Systems for Microservices in the Cloud."

ABSTRACT Recent technology has modeled VANET (vehicular adhoc network) communication well in terms of privileges to derive vehicular communication technologically to save time, energy, and money. Due to the increase in powerful technology in modern times, VANETs play a vital role in uplifting daily concerns across vehicles and vehicular identities. Hence, to tune VANETs to become compatible with traditional technologies and increase demand, VANETs require upgrading. The severity and frequency of unwanted occurrences have become a considerable concern for our day-to-day lives relating to vehicular position. Thus, verily updated methodologies or working procedures are needed for the future VANET interplay to eradicate such problems occurring through vehicular identities. This article outlines in technology related to VANETS, future developments, and coping issues by deriving comprehensive frameworks, workflow patterns, upgrading procedures including big data, fog computing, SDN (software defined networking), and SIoT (social Internet of Things). This article provides a high-level overview of a complete VANET upgrade solution to address future problem management issues under a range of acceptable scientific themes, indicators, and combinations.

INDEX TERMS Vehicular ad hoc network, social Internet of Things, Internet of Vehicle, big data, fog computing.

I. INTRODUCTION

VANETs (vehicular ad hoc networks) are one of the foundation technologies for the current transportation system that is efficient, safe, instructive, and entertaining [1]. People currently spend a considerable amount in automobiles. Smart automobiles based on VANETs have evolved to make that time more secure, efficient, pleasurable, pollution-free, and cost-effective. Today's bustling environment in cities and urban areas may be alleviated by reducing traffic bottlenecks, carbon emissions, and predictable travel times while proving VANET's efficiency in evolving smart cities. VANETs may also have a significant effect in developing recent ITS (intelligent transport system) architecture [2] while connecting to the WAN (wide area networks) across RSUs (road side units) to provide authorized access and data downloads in social media applications [3]. VANETs are becoming increasingly popular. VANETs initially offered by ITSs (intelligent transportation system) to build a safer road transportation systems, are designed to improve traffic safety and management while providing comfort and enjoyment to drivers and passengers on public highways. Recently, vehicular communication has been modeled through VANET architecture employing V2V (vehicle-to-vehicle) [4], V2I (vehicle-to-infrastructure), M2M (machine-to-machine), and V2X (vehicle-to-everything) platforms that must be updated in a timely manner [5]. OBUs (On-board units) in VANET enables connected vehicles to

The associate editor coordinating the review of this manuscript and approving it for publication was Alessandro Pozzebon.

TABLE 1. List of abbreviations used in this paper.

AHS	Automated Highway Systems	**AR**	Augmented Reality
API	Application Programming Interface	**BTS**	Base Transceiver Station
CC	Cloud Computing	**C2C**	Container-to-Container
CRL	Customer Revocation List	**CDN**	Content Delivery Network
CaaS	Communications as a Service	**CA**	Certificate Authority
DMN	Detection of Malicious Nodes	**DoS**	Disk Operating System
DSRC	Dedicated Short Range Communication	**DDoS**	Distributed Denial of Service
EBS	Electronic Break Lock System	**ECC**	Edge cloud Computing
EC	Edge Computing	**FC**	Fog Computing
FeRAN	Fog-Edge Resource Allocation Network	**GPS**	Global Positioning System
GPS	Global Positioning Systems	**HAP**	High Altitude Platform
HAP	High Altitude Platform	**HCI**	Human Computer Interaction
HOV	High Occupancy Vehicle	**IoT**	Internet of Things
IoV	Internet of Vehicles	**ITS**	Intelligent Transport System
IaaS	Infrastructure as a Service	**IP**	Internal Protocol
ITS	Intelligent Transportation Systems	**INaaS**	Infotainment as a Service
LRPON	Long-reach Passive Optical Network	**LTE**	Long Term Evolution
LiDAR	Light Detection and Ranging	**MANET**	Mobile Ad Hoc Networks
MAC	Media Access Control	**MCC**	Mobile Cloud Computing
NaaS	Networks as a Service	**NLoS**	Non Line of Sight
OBU	On Board Unit	**ONF**	Open Networking Foundation
PIL	Packet Inter Loss	**PIR**	Packet Inter Reception
P2P	Peer to Peer	**PCF**	Packet Centric Forwarding
PLC	Programmable Logic Controller	**PDR**	Packet Delivery Ratio
PaaS	Platform as a Service	**PKI**	Public Key Infrastructure
QoS	Quality of service	**RAN**	Rainforest Action Network
RSUC	Roadside Unit Centric	**RSU**	Road Side Unit
SUMO	Simulation of Urban Satisfactory	**SDN**	Software Defined Networks
SaaS	Software as a Service	**STaaS**	Storage as a Service
SIoT	Social Internet of Things	**SIoV**	Social Internet of Vehicles
V2V	Vehicle to Vehicle	**V2I**	Vehicle to Interface
VRSU	Vehicle to Road Side Unit	**VPKI**	Vehicular Public Key Infrastructure
VCC	Vehicular Cloud Computing	**V2RC**	Vehicle to Roadside Communication
VANET	Vehicular Ad Hoc Network	**V2X**	Vehicles-to-Everything

communicate with one other within the RSU infrastructure while forming MANETs (mobile ad hoc networks) to deliver data towards intended users and empower scattered wireless communication. This article discusses some of the recently emerging technologies that VANETs need for satisfactory user experience [6]. This study also identifies opportunities for future VANET research improvement, such as routing problems, device management and acquisition, fault tolerance assurance, latency control, security validation, and privacy concerns. The list of abbreviations is shown in Table **1**.

In a VANET, the user can process, rent, store and share network resources to execute essential applications across a system-based software deployment [7]. RSUs act as an intermediary activity layer to handle typical VANET user loads. In VANETs, RSUs serve as gateways, offering a virtualization layer that enables users to connect to cloud services while on the road. The intermittent clouds in VANET computation include services such as Elastic Clouds, Hybrid Clouds, and Micro Clouds. Moreover, the vehicular nodes employ cloud services to acquire traffic and multimedia data. The design is two-tiered, with vehicles at the network's periphery and the centralized cloud. A cloud-based VANET [8] can have macro control over all automobile's geographic locations, gathering real-time traffic flows while specifying the targeted region and receiver of safety alerts [9], [10] [11].

VANET's within the IoV (internet of vehicles) [12] face varied demands of QoS (quality of service), a difficult issue to address. Future connected vehicles are expected to play a crucial role in the day-to-day replacement of human existence as mobile data collection and data center processing increase. In such cases, the IoV may be able to handle a variety of QoS requests for specific services. In recent times, SDN [13] over VANETs has proved its superiority. As the name implies, SDN is the integration of software devices in VANET. SDN is a technology that focuses on both business and academia because of having a high potentiality of being utilized almost everywhere in the future. SDN is a novel technology that separates control and data within a network design. SDN has centralized control, which allows the network to be dynamic and the network resources to easily be structured efficiently and cost-effectively. In SDN, the control plane and data plane in the VANET are separated so that network intelligence can be centralized and the network's primary infrastructure is separated from the applications.

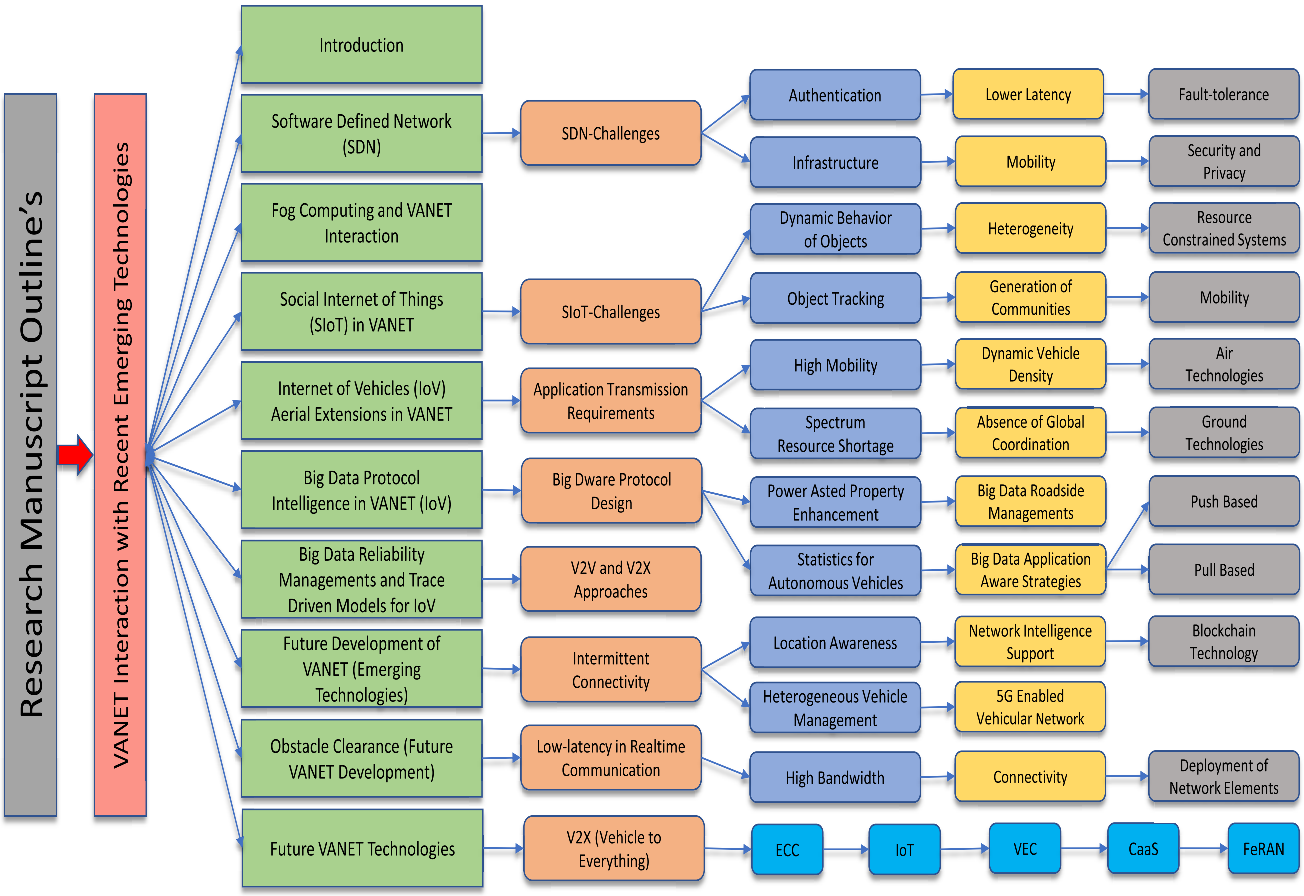

FIGURE 1. Paper organization chart.

Given the immense potential, the VANET system may increasingly benefit from using an SDN controller [14]. In terms of developments in V2I communication, systems that can accelerate traffic movement at intersections depending on traffic demand and alleviate traffic congestion problems are needed. SDN administration and control via VANET are currently alleviating such problems while integrating V2I as a potential infrastructure based on shared data handlers or device interpretations. We present our research organogram in Fig. **1**.

Edge computing (EC) [15] seeks to solve the problems counterfeiting with V2I approaches of SDN within VANET RSU communications. EC uses many Internet-connected IoT devices, storage, and processing capabilities to offer an intermediary layer between end devices and the cloud. 'Edge' devices [16] decrease the computational load on data centers by handling a portion of cloud requests locally, without the requirement of a cloud involvement. Consequently, the time required to resolve request is shorter, and a subset may be processed in real time because of the widespread availability and geographical distribution of edge devices. The edge layer connects end devices to the cloud through separate devices and acts as intermediary edge nodes delivering communication protocols, network data exchange, and shared services across the layer. The three types of widely used edge layer implementations are MEC (mobile edge computing), FC (fog computing), and CC (cloudlet computing) [17]. FC uses M2M gateways, wireless routers, and access repeaters. Fog computing nodes (FCNs) compute and store data from end devices locally before transmitting data to the cloud. On the other hand, MEC [18], [19] integrates storage and processing intermediate nodes over the base stations of cellular networks, allowing cloud computing to be deployed within the radio area network (RAN).

The Internet of Things (IoT) refers to the connection between things and the Internet as a network substrate, specifically with functions such as information exchange and relationships that are not reliant on human involvement. IoT is a recently coined term that refers to the connection between objects and the Internet as network infrastructure and comes from merging SNs (Social Networks) with IoT [20]. Furthermore, objects may initiate social interactions on their own, and communication between them can be as essential as utilizing smartphone apps such as waze to find the fastest route or as complex as a smart city's communication medium. SIoT [21] created a social network based on common interests and the ambition to provide services to end-users by linking all networked devices worldwide. This SIoT [22] could play a vital role in VANET frameworks while ensuring smooth social interactions between humans and IoT-enabled smart vehicles. To send or receive data from a certain platform or user application, devices must be connected to the Internet or a gateway, either directly or indirectly. As a middleware, global connections link items to each other and serve as a communication layer between platforms and devices while employing communication standards, gateways, and protocols (MQTT, HTTP, and HTTPS) to read and send data over Internet objects.

VANETs employ a vehicle, RSU, a base station (BS), traffic infrastructure (traffic lights, CCTV camera), GPS data, and other sources of information to establish a feasible ITS environment [23]. The aforementioned sources use many sensors and CPUs to generate massive amounts of data. Data come from various sources, including mobile devices connected to the VANET. The quantity of data generated [24] is essential information that can be used for several reasons, and those data offer several advantages, in terms of both business and developing environmentally friendly data management systems. The VANET data can also assist in making more informed decisions about our ITS portfolio. In the ITS era, the volume data is expected to expand at an astounding rate. This vast quantity of data greatly exceeds the processing power of standard database systems. For usage in VANET applications, the term ''big data'' refers to enormous, diverse, and complicated datasets obtained from various data sources. It includes sensors, GPS, and other publicly available information in vehicular networks. These unprocessed data sets are frequently associated with varying levels of proficiency. The emphasis focuses on GPS data and other sensors installed in automobiles, providing reasonably simple figures. Collecting, processing, and analyzing this data, on the other hand, poses considerable technological problems, necessitating the creation of novel vehicular network solutions [25].

This paper presents the latest trace-driven possibilities that focus on VANET management and provides substantial new research direction. The central insight of this work is to provide possible hints to future VANET researchers and developers, illuminating possibilities by delving into vehicular intelligence options. Moreover, the paper provides an insight to conduct and show good research directions over challenges and opportunities within VANETs by leveraging big data around the IoV platform [26], high altitude platform (HAP), Software Defined Networking (SDN), cloud, Social Internet of Things (SIoT), Long Term Evolution (LTE), Internet of Vehicles (IoV) and fog computing.

Some major outcomes of this paper are given below –

- We investigate VANET approaches and possibilities in recent emerging technologies perspective such as SDN, SIoT, fog computing, and Big data.
- We focus on different VANET services and architecture, orchestrating the fog computing taxonomy.
- We review VANET-based systems and highlight the particular developments that can help security and cost management purposes.
- We compare different VANET services in terms of reliability and computational power integrating cloud, LTE, and IoV.
- We outline the recent technology-based VANET overall challenges and open issues for VANETs future development.

The rest of this paper is organized as follows. Section **2** provides an overview of the SDN architecture. Section **3** investigates the VANET interaction with fog computing. Section **4** focuses on the impact of the SIoT in terms of VANET architecture. Section **5** summarizes the significance of the IoV. Section **6** summarizes the impact of big data reliability management with trace-driven models. Section **7** identifies the technology-based VANET challenges. Section **8** discusses the open issues that hinder the future development of VANET technologies. Last, we provide the conclusion in section **9**.

II. SOFTWARE DEFINED NETWORKS (SDN) FOR VANET

The SDN is a novel technology used in conjunction with edge Cloud computing, notably Fog computing, to allow centralized network management, flexibility, and programmability. OpenFlow is the most widely used protocol for communication between SDN control planes and their operations. As a consequence, by allowing the OpenFlow user manufacturer to supply new services and administrative tasks, the management of resources and vehicles can be improved [27].

The fundamental SDN-edge control architecture in terms of services is depicted in Fig. **2**. Using the control plane's programmability characteristics, users may build, configure, and program network capabilities such as topological management, network orchestration and abstraction, different types of service mapping, and intrusion detection and prevention systems. The three layers that make up the system are the software layer, the manage layer, and the community layer. The SDN controller communicates with the application layer via northward interfaces, and the northbound interface allows programmers to use the software to influence the community. At the community layer, the southbound interface talks with the SDN controller and community devices [28], to create an east-west bridge mechanism for intradomain communication within the Associate in Nursing SDN. The community units based solely on Open-Flow accept SDN controller rules without implementing various network protocol standards, resulting in indirect asset management, programming, and management. Open-Flow, which also defines a route from supply to destination, is used to control SWIFT program allocation (Software Defined Wi-Fi Flow Management). This approach Improves the network speed and decreases router

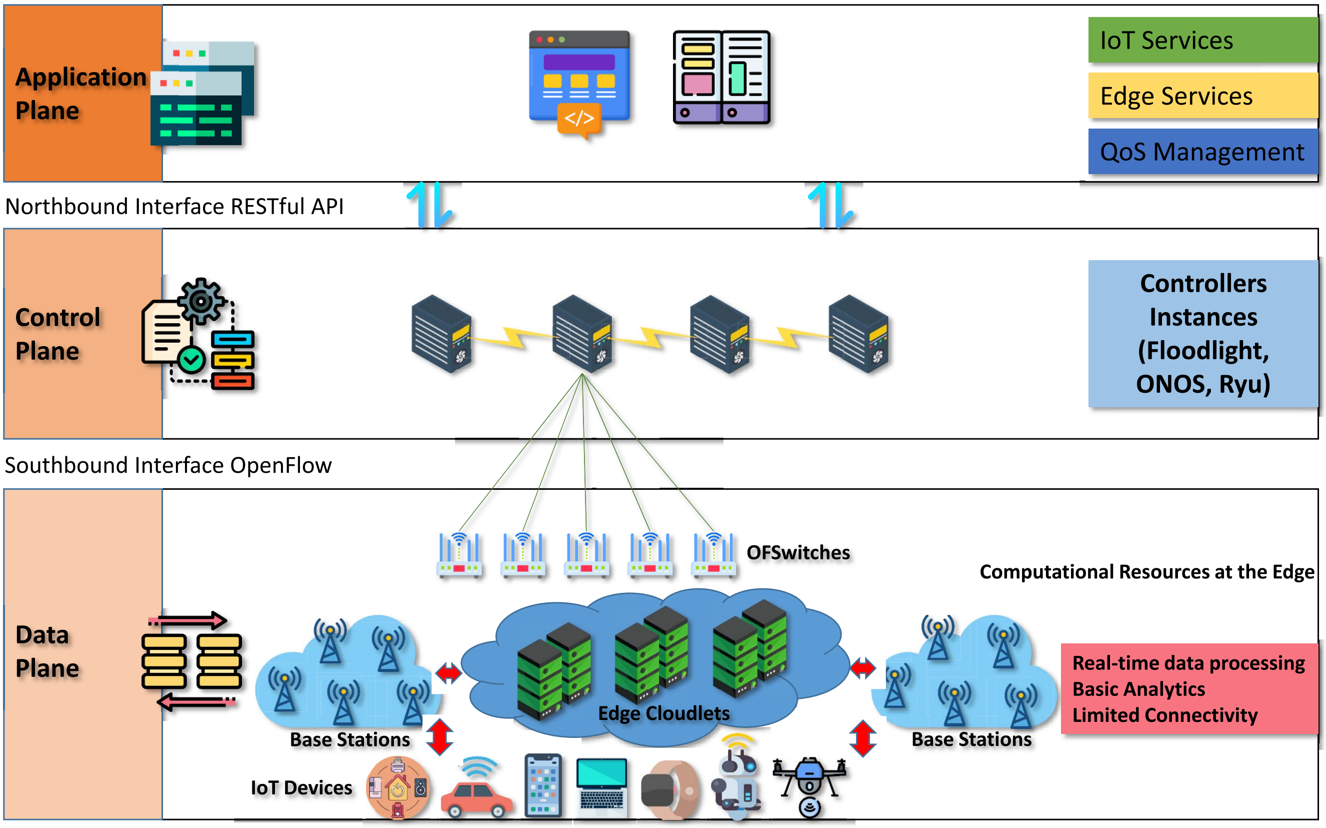

FIGURE 2. SDN-Edge architecture for three separate planes in terms of its services.

packet overhead while shaping the trail. It also lowers the cost of network administration.

A. SDN: CHALLENGES

We investigate the requirements of SDN infrastructure for the SDN paradigm [29] to be implemented efficiently in Table 2. SDN-IoT uses network resource virtualization to offer services to heterogeneous devices. The trend away from hardware-based solutions and software has resulted in low-cost IoT applications. In this way, the SDN-IoT paradigm's needs must be effectively envisioned prior to any practical deployment. By using SDN's centralized management approaches, resource restrictions in IoT devices may be successfully managed by bringing resources closer to the edge devices. In the next sections, we address the most important needs, issues, and solutions.

- **SDN Management:** Network scalability, manageability, and efficiency requirements may all be met thanks to the centralized management capabilities of SDN-oriented systems. SDN-based solutions must be developed to offer effective administration, such as load balancing, efficient traffic management, and concise bandwidth usage. Additionally, the A-CPI (Comprehensive Packet Inspection in Assembly language) and C-DPI (Deep Packet Inspection in C programming) standards will solve IoT-Edge management issues such as traffic forwarding, network latency, load balancing, and heterogeneity [14], [29].
- **Authentication:** Different communication technologies in SDN-IoT utilize a variety of security protocols, which inevitably result in the formation of local trust domains. In this instance, the challenge of credential distribution across several sites occurs, preventing an efficient global trust paradigm. The creation of global authentication policies for a wide range of networks and infrastructures is one solution to these issues. Existing systems employ a certification authority that distributes session keys to authenticate devices in their own trust domain [13].
- **Heterogeneous Infrastructure:** Large-scale IoT manufacturing, where market vendors produce nonstandardized IoT items to make more money, causes interoperability issues. Although it lowers infrastructure costs, most of the products developed are vendor-specific and have interoperability issues [13]. A vendor-independent environment is required to address the issues of diverse manufacturers. SDN has the ability to break away from vendor reliance thanks to continuing standardization efforts by the open networking foundation (ONF). Consequently, numerous wireless sensor networks (WSNs) and body area networks with different underlying technology can work together seamlessly [29].

TABLE 2. A comparative study of main challenges of SDN infrastructure among available technologies and their solution approaches.

Challenges	Research Dimensions	Solution Approach
SDN-IoT Management	– Traffic isuues objects – Network delays	Implementation of A-CPI (Comprehensive Packet Inspection in Assembly language) and C-DPI (Deep Packet Inspection in C programming)
Authentication	– Authentication of multiple devices – Credential distribution issues	Implementation of Global authentication policies
Heterogeneous Infrastructure	– Vendor-dependent products – Multi-infrastructure interoperability protocols	Virtualization standards for SDN-IoT
Traffic Management	– Diverse orchestration requirements – Traffic congestion issues	Efficient application development
Lower-Latency	– Real-time applications need lower latency solutions – Lack of effective offloading solutions	Customized offloading solutions
Mobility	– Lack of mobility-aware VM migration – Real-time VM handling	Mobility-aware VM migration
Fault-Tolerance	– Lack of backup channels – Changes in the network connections	Data classification techniques
Security and Privacy	– Location-based privacy issues – Platform-specific security policies	Lightweight authentication solutions

- **Traffic Management:** IoT data may be preprocessed at the edge, decreasing the computing load on the cloud. SDN-IoT addresses the congestion problem inside the leading network and datacenters by dispersing traffic to independent edge servers. However, the orchestration requirements of application-specific request processing, which requires innovative traffic dissemination methodologies, necessitate unique traffic dissemination strategies to route traffic according to user expectations. SDN-IoT traffic distribution can be aided by customized traffic forwarding systems that utilize the SDN's centralized management. Application requests should be routed by comparing them to requests received at intermediate nodes, which will decrease the associated cost, network load, and traffic delays [13], [29].
- **Lower Latency:** Online gaming, virtual reality, and ultrahigh-definition video streaming are examples of real-time applications requiring exceptionally high data access rates and low latency. Existing edge solutions are particularly vulnerable in such scenarios due to the massive volume of data created by the IoT. In addition, the standard authentication procedures used by IoT and edge devices increase the request delay. Traditional offloading systems introduce latency into the service orchestration process, necessitating the development of efficient offloading solutions to meet the IoT's latency needs [14], [29].
- **Mobility:** SDN applications are highly mobile. When a user moves, the distance between the relevant servers grows, degrading the user experience. Users' spatial preferences are relayed to edge servers through their journey in these apps, which may be leveraged to improve service orchestration efficiency. This approach is then used to find the best location for transferring the service to improve the customer experience. However, this approach is designed for the central cloud; therefore, SDN-IoT will require considerable changes. As VMs go to the edge, SDN offers the ability to monitor and control them [13].
- **Fault Tolerance:** Failure prevention in SDN-IoT may be accomplished via backup offloading lines. In addition, micro BSs or central clouds with more extensive coverage can enable fault tolerance to deliver seamless edge services. Providing appropriate QoS and energy consumption for backup connections and maintaining protective clouds for single-user and multi-user edge computing is a challenge. Finally, data collected through

intelligent inspection methods at specified intervals and feedback about services are related to defect detection. In addition, time-saving channel and mobility characterization methodologies would enable fault discovery. The fault recovery mechanisms should work to prevent interruption of the currently running services [14].

- **Security and Privacy:** Network infrastructure security is one of the most important concerns in a heterogeneous environment with multiple users, devices, and providers sharing a single platform. On the other side, IoT service orchestration requires data flow to several parties. Control of these devices should be assigned to the relevant hosts that deliver services since numerous suppliers operate the network infrastructure. IoT infrastructure creates data, which are then sent to local edge servers, limiting the scope of the data and enabling the development of security processes. Because the data originator's identity may be disclosed depending on the location, data interaction across platforms raises location-based privacy concerns. Similarly, service providers must obey regulations when obtaining large amounts of data from encrypted sources [13], [29].

III. FOG COMPUTING AND VANET INTERACTION

Fog computing is a technique related to data computing and storage. If an application is stored between data, cloud fog computing can be used. Fog computing is like a bridge between data and the cloud and is essential for IoT devices. We outlined fog computing via an SDN controlling architecture using the control plane's programmable features in Fig. **3**. When a vehicle senses a pile-up, it sends a broadcast IP address to a nearby RSU. RSUs then transmit the protection message to the switch, which reaches a router since it was sent with a broadcast IP address. A router must regard a broadcast security message as a special message. When the router receives security messages with a broadcast destination IP Address, it sends them to the fog server for processing. The type, substance, timeliness, and importance of the received event are all checked by the fog. Moreover, VANETs are a key technology for creating a transportation system that is effective, clean, insightful, and entertaining [1].

People spend a considerable amount of time in automobiles. Smart vehicles based on VANETs have emerged to be safer, more reliable, enjoyable, pollution-free, and cost-effective. Greater protection can be achieved by ensuring the reliable exchange of vital incidents. Reduced road traffic and noise and more predictable travel times contribute to increased productivity. VANETs can also be linked to the Internet to make trips more enjoyable by providing file downloads and links to social media [3]. Beacon and protection messages are two kinds of messages used in VANETs. Automobiles employ beacons at 100 ms intervals to communicate and advertise status changes to surrounding vehicles. The transmitter emits beacon signals to neighboring automobiles to convey its velocity, position, and pseudo-ID. On the other hand, safety warnings aid drivers on the road

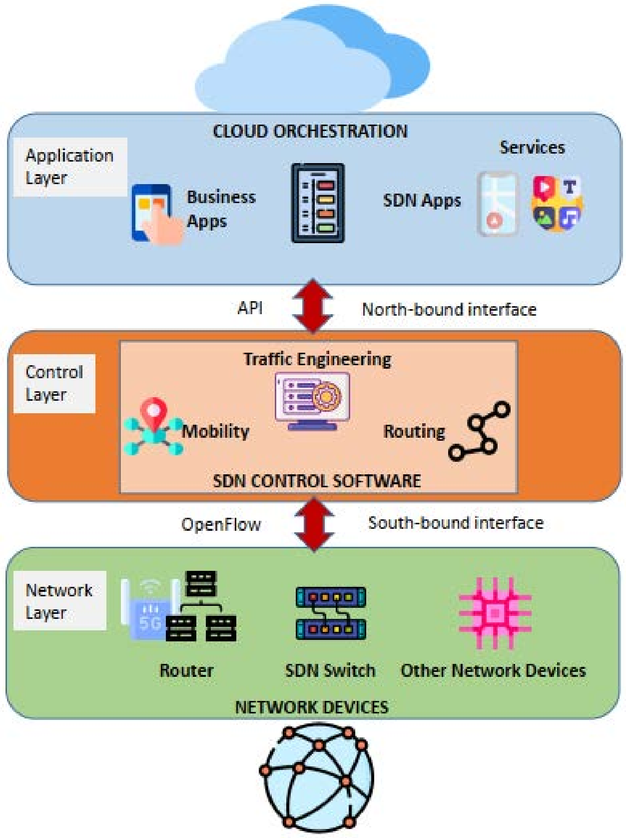

FIGURE 3. Overview of Fog computing through SDN controlling architecture using the control plane's programmable features.

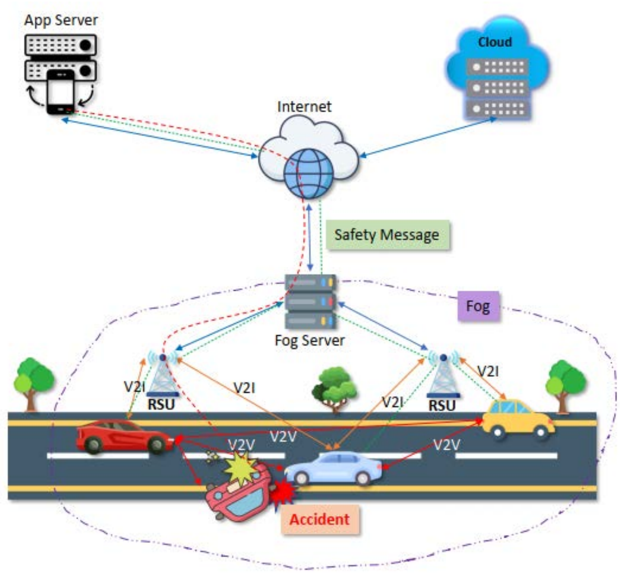

FIGURE 4. Fog computing architecture for security and safety messages promoting in VANETs.

by providing information that allows them to take necessary actions to avoid collisions and save people from potentially fatal circumstances. When a car meets a problem on the road, it transmits a WAVE short message (WSM) to surrounding

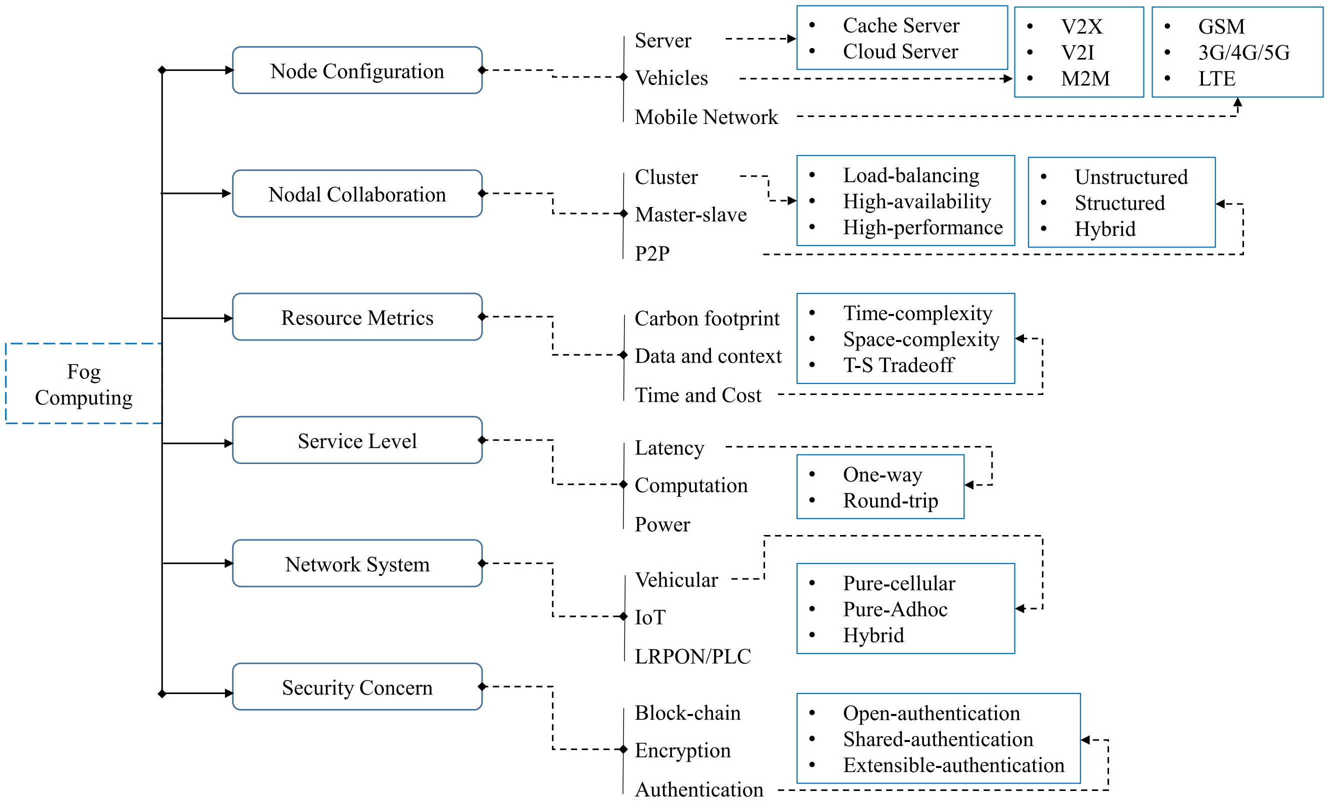

FIGURE 5. Generic fog computing taxonomy emphasizes identifiable issues and existing work plans.

cars. The vehicle's direction, the time the message was sent, the vehicle's position, and nearby road events are all part of the message payload. Each automobile in a region collects data about the cars within its contact range. The vehicles' OBUs are equipped with IEEE 802.11p and long-term evolution (LTE) cellular technologies in heterogeneous VANETs. For data collection, processing, administration, sophisticated calculation, and global networking, VANETs rely on the traditional cloud. Software as a service (SaaS), application as a service (PaaS), and infrastructure as a service (IaaS) are three major delivery models for cloud services in the form of tiers. As a result, customers may rent computing, storage, and network resources to install and operate devices and applications they need. Customers in this situation may have nearly infinite finances that are dependent on their budget. Elastic Clouds, Hybrid Clouds, and Micro Clouds are examples of cloud computing services.

To process or route an incoming packet, OpenFlow devices use flow tables, which are composed of flow entries, as shown in Fig. **4**. The switch forwards each incoming packet by examining the flow table entries and matching the header field of the incoming packets. It can then decide if it finds a match. If no match is found, the packets are sent to the SDN controller to be processed. The control layer also includes quality and route managers. The mobility manager at the management layer is in charge of putting together and monitoring the status of all SDN switches, RSUs, and vehicles. Because of their high speed, vehicles may become detached from the management plane for a brief time. Route prediction may be used to forecast the likely position once the automobiles have been separated. The GPS or navigation system in a car can be used to predict a vehicle's future route [30]. It can also control event detection and, as a result, the policy for updating the switch status. The routing manager keeps track of the network topology with the aid of SDN switches. Furthermore, the network architecture of stationary data plane devices rarely changes, but the network structure of mobile data plane devices is dictated by the neighbor data acquired. The SDN may be utilized to satisfy the requirements of future VANET systems and improve VANET services in various contexts because of these capabilities. A generic diagram of fog computing taxonomy is shown in Fig. **5**.

IV. SOCIAL INTERNET OF THINGS (SIoT) IN VANETs

The number of vehicles is growing rapidly with millions of automobiles worldwide, leading to unforeseen trouble in the future. However, the presence of popular methods to test visitors' domain to a site is centralized and is not

understandable due to issues related to time, fees, and scalability. Trending instances known as SIoT can perform a necessary task to overcome the complexity of site visitor domain centralization analysis. The SIoT was created by combining social communication principles and the IoT.

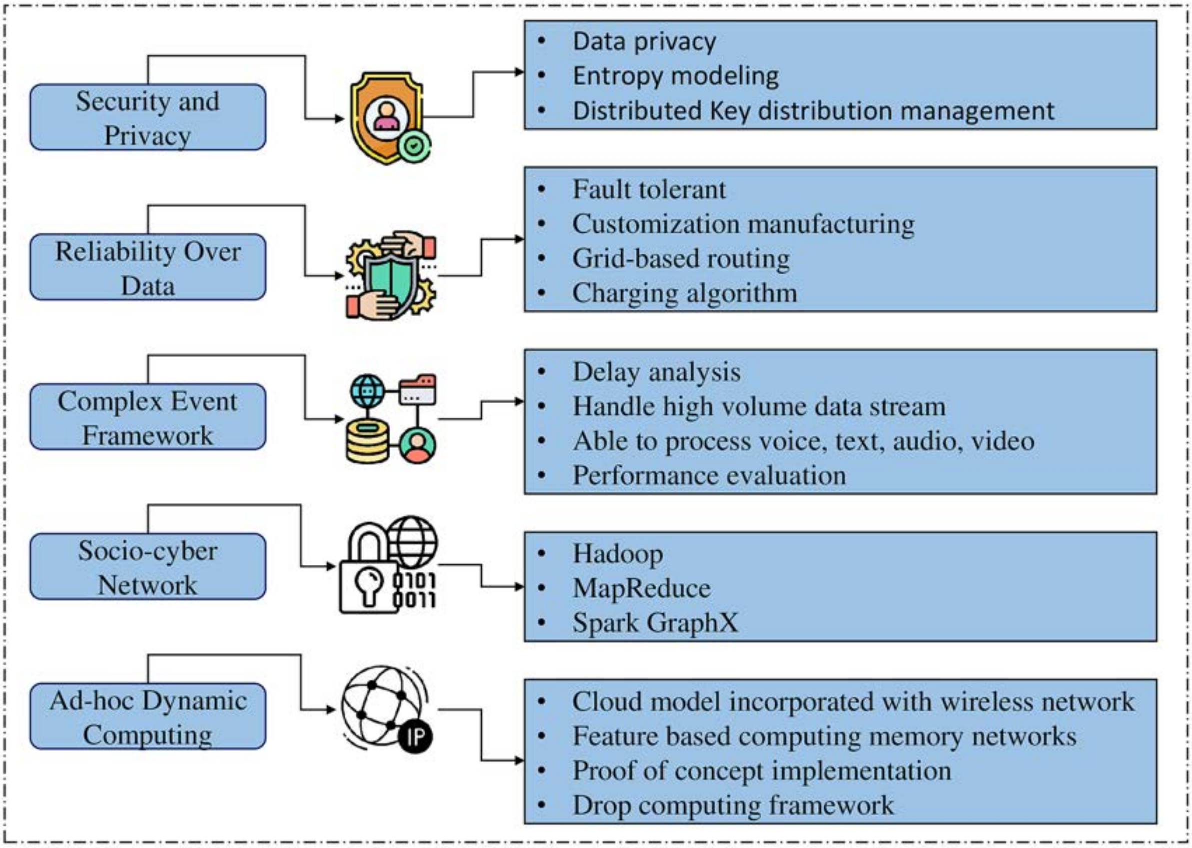

FIGURE 6. **SIoT technology usage in different sectors in terms of its services.**

The objective is to create a platform that allows all IoT to interact, share, and seek services of their choosing in an ever-evolving way, without requiring global knowledge of the entire network illustrated in Fig. **6**. The SIoV (social Internet of vehicles) is a vehicular version of the SIoT. Each car in the neighborhood acts as a smart decentralized IoT, communicating with other cars by stopping at specific distances and forming a complicated network. A sophisticated traffic zone mapping algorithm has been built across complicated networks using social and verbal exchange approaches. The findings indicate a lucrative application of the megacity, to enhance road safety management to minimize accidents and traffic issues in the VANET combined region by monitoring social behavior and ambitions [31]. Viewer domain analysis may be environmentally friendly and meaningful when studying certain essential network elements obtained from a social network of cars.

A. SIoT: CHALLENGES

Many SIoT challenges [32] may be critical for academics to solve to develop innovative solutions. In this paper, we identify and describe the main challenges and potential solutions in Table **3**.

- **Heterogeneity:** SIoT consists of millions of objects with different sources, platforms, protocols, and standards, all of which must be recoverable. These distinctions have resulted in the construction of a heterogeneous network of items, which directly impacts their interaction and compatibility with one another, thereby increasing complexity. As a result, the heterogeneity of objects creates a variety of issues, including interoperability and compatibility, that must be addressed.
- **Mobility:** In a dynamic environment, smart objects constantly change location, causing challenges such as a lack of effective object search for selecting and delivering services. Another important subject is the dynamic behavior of things and their environment, leading to object state changes.
- **Generation of communities:** To address the issue of mobility, groups of objects can be grouped into communities based on common traits such as movement, social behaviors, social similarities, and mutual interests. As an object adjusts its position, the community's structure changes. Consequently, we may use Euclidean, adjacent matrix, or GPS algorithms to extract the current position of objects and compute their distance, which is then utilized to create location-based traces for SIoT devices.
- **Dynamic behavior of objects:** To prevent the network topology from changing, objects must have specific fundamental rules and protocols designated by their owners to manage such changes. However, because an object must respond to frequent changes, adaptation is another difficulty that arises.

TABLE 3. A comparative study of main challenges of SIoT among available technologies and their solution approaches.

Challenges	Solution Approach
Heterogeneity	• POR (Picture of Reference) object relationship and middleware (interface) for non-POR (Picture of Reference) objects • Policies for objects identification
Mobility	• Objects movement (use Euclidean distance, GPS functions, SWIM model) • Dynamic changes by owner rules and protocols
Dynamic Behavior	• Social Similarities • Common Interests
Object Tracking	• Based on objects social behavior on Graph model • Using objects movement patterns (GPS, 3D location-based approaches)
Security and Privacy	• Access control system (prevent unauthorized access) • Trust management framework and safe data sharing model
Resource-constrained System	• Efective resource management system • Optimal solution to address this problem

- **Object tracking:** One of the greatest difficulties with SIoT and large-scale networks that has remain unaddressed is tracking objects, interactions, and activities. Some rules must be developed to define how edges between two items are built, updated, forecasted, or deleted. Any item can be considered the central node, and their relationships create their edges. Depending on the type and element of a pair of objects' relationship, such as a common interest, providing a particular service or services, being in the exact location, and so on, their actions entail greater weight.
- **Security and privacy:** Because the SIoT includes such a huge connected ecosystem of devices, opportunistic services, and users, data security is crucial. Although different forms of research have addressed this issue, it remains a fundamental challenge that must be solved for the system to withstand several assaults while maintaining security, reliability, availability, and resiliency in interactions.
- **Resource-constrained system:** Although the SIoT is a resource-limited system, and this issue has a direct impact on the network's life and information exchange, there remains no optimal solution to address this issue by taking energy constraints into account at all levels of design to ensure more effective interactions. Thus, further research and study are required to design an effective resource management system for the SIoT to maximize its potential.

V. INTERNET OF VEHICLES (IoV) AERIAL EXTENSIONS FOR HETEROGENEOUS DEVICE INTERACTIONS

Because of the diversity of verbal network exchanges, big data are difficult to transmit over the IoV due to the large number of data picks and data volume, such as strict QoS. The transition requirements for unique IoV purposes are provided and represents a challenge for modern-day VANETs. The transition approaches are then categorized and summarized for one-of-a-kind applications. For cut-edge IoV, both MAC and routing protocols are investigated. A high-level design paradigm of such IoV platforms in terms of cloud computing, LTE or 5G is shown in Fig. **7**.

- **Applications and Transmission Requirements:** Mobile advertising programs have picked a variety of tiny public automobiles such as taxis and buses to promote digital advertising. Each vehicle is required to periodically record its information, including position, speed, title direction, acceleration, and signal position to all nearby vehicles. These capabilities necessitate a reduced transmission rate due to the small size of security messages, which are generally 200-500 bytes (DSRC Committee, 2009). In contrast to safety warnings, such announcements or ads may be broadcast over greater distances to alert drivers of larger vehicles on the road. Through the connection between the seed motor and others in a broad area, commercial records may be continually revealed throughout the network [33].
- **Harsh Wireless Channel Conditions** Tall structures, tunnels, overhead bridges, extended roadways, and the state of time-altered site visitors all have a substantial and dynamic influence on V2V hyperlink performance when utilizing scenery. Wi-Fi channels become unstable as a result of these barriers and multipath fading [34].
- **Spectrum Resource Shortage:** In the DSRC standard, one control channel (CCH) and many service channels (SCH) provide optionally available bandwidths of 10 MHz and 20 MHz. The FCC, on the other hand, has allotted the DSRC 75 MHz of licensed spectrum, which is insufficient to direct IoV transmission in high-density situations for media-rich applications [35].

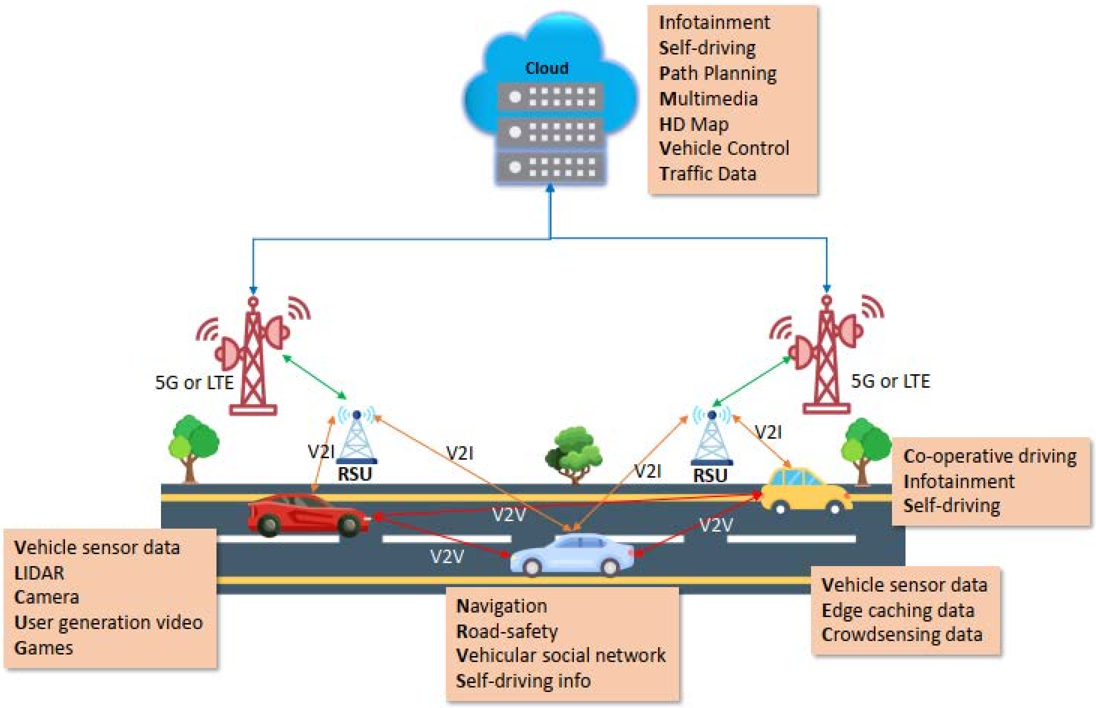

FIGURE 7. Cloud to LTE or 5G VANET communication and information exchange scenario in IoV platform.

- **High Mobility:** Wi-Fi connections between moving automobiles and limited-coverage road infrastructure would be regularly disrupted due to excessive traffic on the road. Furthermore, channel effective resource allocation, routing protocol structure, and message receipt are all influenced by speed, acceleration, road layout, visitor lights, riding behavior, and movement related to site visitor regulations [36].
- **Dynamic Vehicle Density:** Vehicle density can be relatively high in a city or highway, while it can be exceedingly low in suburban or highway regions [37]. The open and essential question is how processes can successfully respond to different vehicle densities so that channel aid is not wasted in low vehicle densities and channel congestion is minimized in high vehicle densities.
- **Absence of Global Coordination:** The installation of a central coordinator for IoV is problematic because IoV covers a wide range of community admissions and spans large geographic areas. IoV transmission techniques attempt to accommodate these constraints and operate in a dispersed manner.

A. AIR TECHNOLOGIES IN VANET

Space and aerial platforms are not only a vital complement to large data gathering techniques for IoV, they may also increase overall network capacity [38], [39]. IoV connections offered by networks such as RSUs and cellular base stations might be unavailable in rural regions. Due to high site visitor demand and scarce Wi-Fi resources, meeting IoV requirements in dense car areas is challenging. Because of the additional conversation options provided by the aerial network, IoV connectivity can be enhanced. Satellites' capacity to fulfill communication duties has previously been demonstrated by GPS and other successful geo-location-based applications [40]. A high-altitude platform (HAP) has also been demonstrated in previous studies to be a suitable and economical solution to offer broadband network services in sparsely inhabited areas [41]. Satellites can offer comprehensive coverage for automobiles, including those in remote locations, while the HAP will provide temporary connections in response to complex IoV transmission needs. Due to drones' high flexibility, HAP and drone platforms will have extra spectrum capabilities in crowded vehicle settings, which will not only increase verbal interchange capability but also provide a diversified source that can respond to IoV spatial and temporal alterations [42].

- **Satellite:** In today's IoV, systems such as GPS are primarily used to collect and transmit vehicle location records. To improve positioning accuracy, related studies combining IoV with satellite TV for PC systems use a variety of applied sciences [44].
- **High Altitude Platforms (HAPs):** HAPs can improve the IoV's overall efficiency in two ways: 1) as community infrastructure for cars in distant settings and 2) as extra spectrum assets for the IoV in dense scenarios. Furthermore, broadband communications can be guided by HAPs [45]. We demonstrate the overall scenario

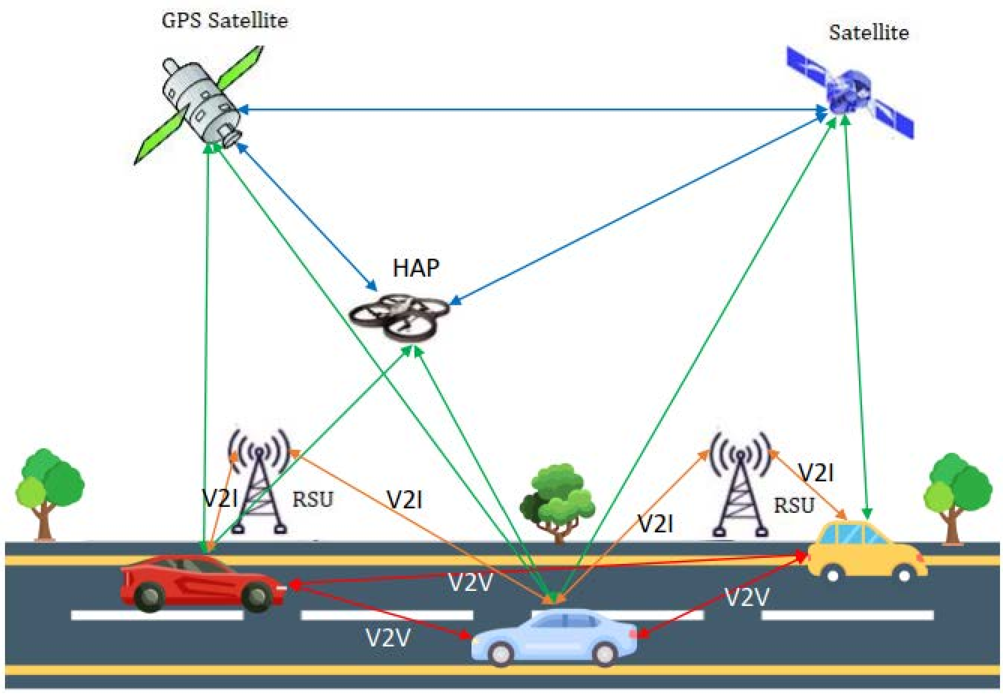

FIGURE 8. VANET communication throughout high altitude vehicle platforms (HAP) and other IoV sensor objects [43].

regarding the IoV with HAP in terms of air technologies in Fig. **8**. The transmission requirements of various IoV applications, as well as the current VANET challenges, are reviewed. The relevant transmission strategies for diverse applications are then classified and summarized. Finally, the current IoV's MAC and routing protocols are then examined.

B. GROUND TECHNOLOGIES IN VANETs

- LoS A2G (Line-of-Sight probabilistic Model for Air to Ground) Connections: Due to the frequent blocking of one-hop record links for vehicle-to-vehicle (V2V) and vehicle-to-roadside (V2R) communications, aerial platforms, particularly the HAP and drone, have proven to be extremely capable of providing the LoS A2G verbal exchange, thereby improving insurance and communication [46], [47].
- **Dynamic Deployment:** Due to space and economic constraints, traditional infrastructure renovations and developments are inefficient. Because the facilities are permanent on the site, it is difficult to adjust to the IoV's changing knowledge visitor demands. In the IoT, the role of the house and aerial structures has been widely explored and analyzed, notably for rockets, HAPs, and flying drones [48].

VI. BIG DATA PROTOCOL INTELLIGENCE IN VANETs

This section derives, specific IoV characterization and the outcomes of the large information-assisted mensuration. However, field information collection, contact procedures for IoV may be built much more efficiently and correctly to get good results over VANET-IoV interplays [49], [50].

- **Big Data-Aware Protocol Design:** Data abounds Designing Conscious Protocols: As previously stated, the enormous amount of data entails persuasive recommendations for configuration modeling and channel modeling, which are both critical for developing and testing acceptable spoken communication protocols [51], [52]. Furthermore, the MAC and route protocols would be better equipped to adapt to the IoV's spectacular and often dynamic topology with significant data support, such as giving feature information [53].
- **Big Records Power-Assisted Property Enhancement:** The group property in the IoV may be increased with the use of large documents. A bandwidth reservation theme with consciousness of the great predictor was previously developed to scale back the packet loss rate in the soccer play process by combining handoff time estimation (HTE) and the provided statistics calculate estimation (ABE) topic. UAVs were utilized by Abbasi *et al.* to collect visitor data and drive the bottom motors to efficiently guide visitors to information sites [49].
- **Big Data Statistics for Autonomous Vehicles:** For radical independent vehicles, massive IoV recordings are a key facultative technology. A massive quantity of data is needed to bring self-driving to life, including onboard sensors such as cameras, radar, LiDAR, and GPS, and data provided by other vehicles, such as

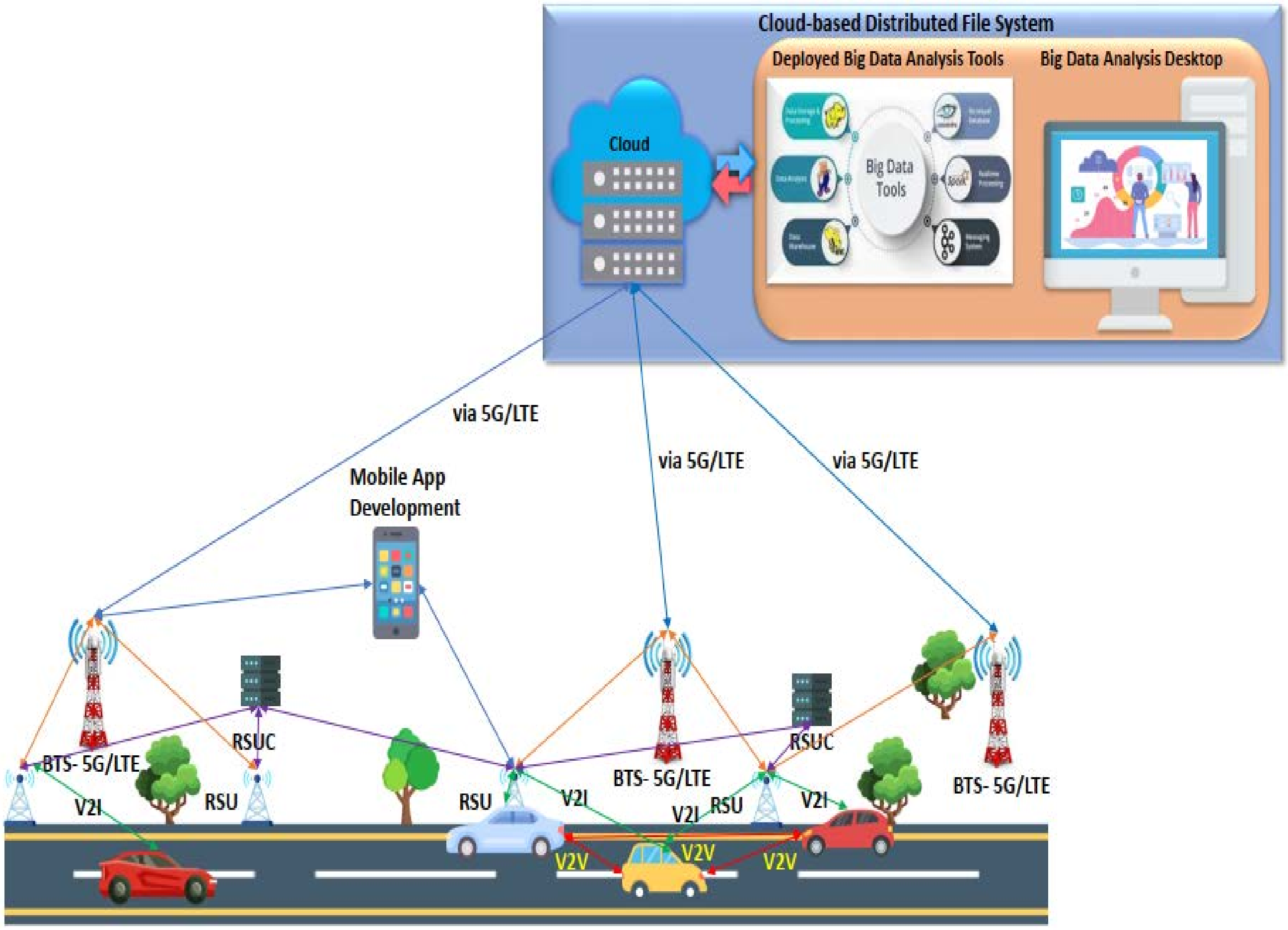

FIGURE 9. Big Data application aware strategies and protocol intelligence.

road conditions and information about on-site visits. According to projections, a self-driving car would create roughly one petabyte of data per hour. To drive safely and effectively, vehicles must be able to observe their surroundings and make judgments based on all available data, ecologically sustainable control systems [20], [50] and massive processing and storage capacity. A parent may also be presented in autonomous mode, exhibiting the large statistics features. The capacity to comprehend location is a unique uses of IoV big data in self-driving cars. LiDAR and HD map technologies are employed to provide relevant statistics. VANET networks are combined with LTE or 5G networks to create a hybrid Cloud-VANET with minimal network overhead, high mobility management, and high coverage, as shown in Fig. **9**. LiDAR is a type of sensing technology that uses spinning optical maser beams to scan a car's immediate surroundings and create statistics called "point clouds" that contain high-resolution data. The technology and upkeep of the HD map, are time-consuming processes that need a fleet of automobiles equipped with LiDAR calculations while on the road, which may be expensive. By decoding ground and aerial pictures, Mattyus *et al.* [17] proposed an avenue segmentation technique that infers the linguistics of roadways.

- **Big Data Roadside Management for VANET:** The IoV's wide range of statistics may also be utilized as a mirrored image of the IoV, which is useful in IoV characterization because it has a lot of contributing factors and is difficult to describe. Floor testing has shown that portraying downtown, residential, industrial, open fields, and highways in the IoV can be made more accessible. Bai *et al.* investigated the influence of various components on core V2V contact characteristics using a black field structure. The packet delivery ratio (PDR), which is discussed in [54] is the most critical indicator of V2V connection efficiency. The study of correlation functions such as temporal, spatial, and isosceles correlation, is also important.

A. BIG DATA APPLICATION-AWARE STRATEGIES IN VANETs

Transmission approaches must be developed in automobiles to enhance the records transmission dependability in the IoV

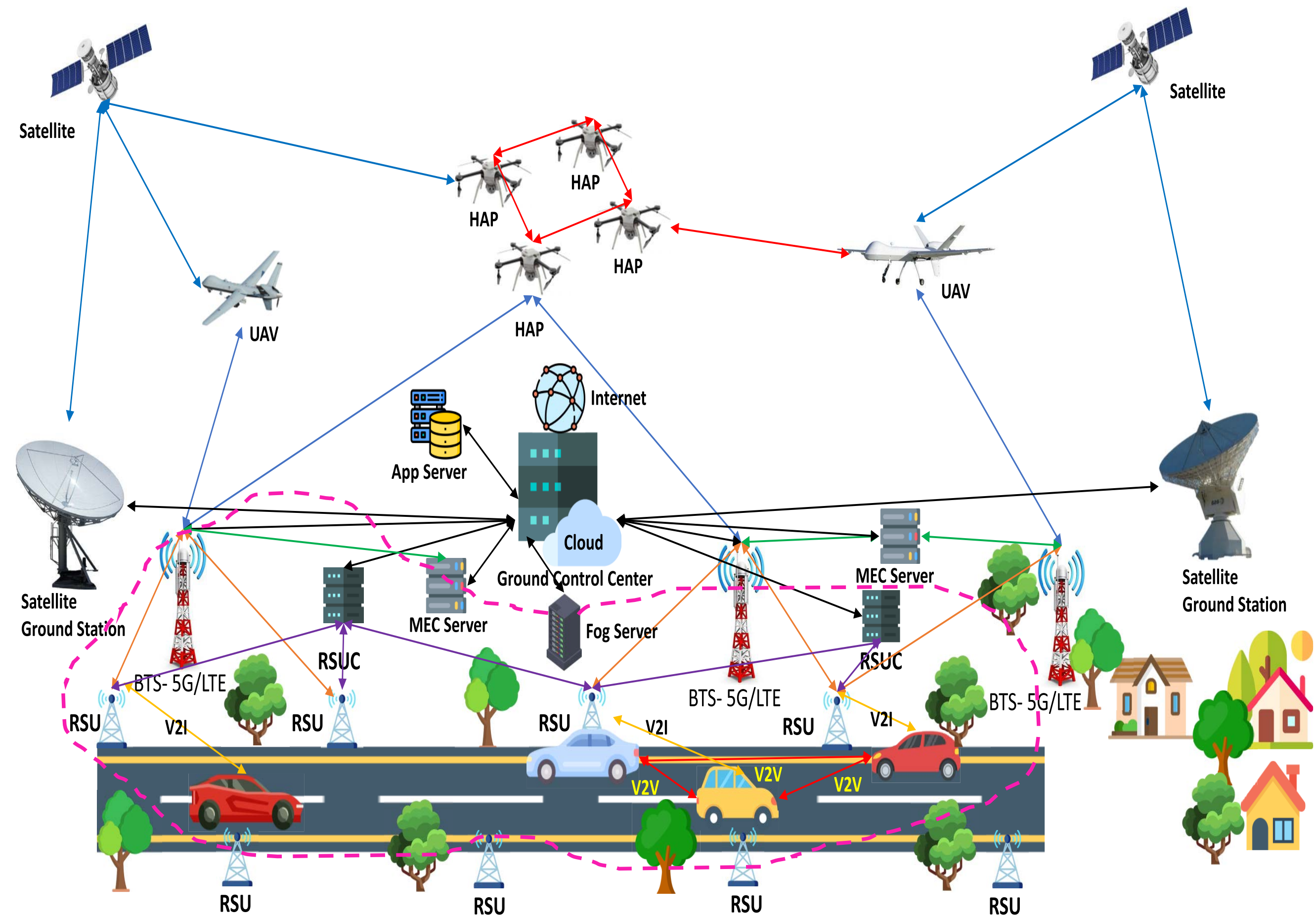

FIGURE 10. Big Data trace driven working pattern in IoV (V2V towards V2X approach).

to acquire the goal messages from the massive amount of data. There are two types of goal message delivery systems under investigation: push and pull.

- Push-based Strategies: Push-based methods attempt to reach as many individuals as possible with desirable signals, such as security alerts. Flooding is the most basic kind of transmission, in which each vehicle sends data packets to all of its one-hop neighbors. The message is delivered to all receiving neighbors again, and the process is repeated until all multi-hop neighbors have received the target message. However, flooding easily results in a transmitting tornado, in which multiple vehicles within the contact spectrum broadcast simultaneously, resulting in the loss of a large number of packets due to transmission collision. Furthermore, it is not uncommon for certain packets to be transmitted excessively several times, resulting in channel asset waste in the IoV [55]. Several techniques have been established to minimize packet transmission overhead and restrict the range of collisions. For example, cars are assigned an exclusive rebroadcast probability in the weighted p-persistence method which enables vehicles located farther from the transmitter to rebroadcast with a higher likelihood of success. Furthermore, cars replay packets that are received for the first time and ignore packets that have been received previously.
- Pull-based Strategies: Pull-based methods use the request-response mechanism to distribute target signals [56]. Pull-based techniques have less overhead than push-based methods, but they can result in greater delay due to the request-response agreement required before transmission. The transmission of IoV data between vehicles and spine-connected bodies, such as distant Internet servers or peers, is accomplished mostly via pull-based approaches. To minimize the latency [57] of pull-based methods, statistics caching is frequently implemented to increase the statistic distribution productivity by storing the necessary information in infrastructure [58] near vehicle consumers [59].

B. BIG DATA RELIABILITY MANAGEMENT AND TRACE-DRIVEN MODELS

The large statistics in IoV might also be used as a mirrored image of the IoV, which plays an essential function in IoV characterization that involves many influencing factors and places units that are difficult to model. Some experiments have already shown that the size facts will signify IoV in urban, suburban, rural, open fields and freeways. Bai *et al.* [60] proposed a black field framework to assess the impacts of different elements on key V2V communication characteristics. The packet delivery ratio (PDR) is examined in [54] as the most important metric of V2V communication dependability illustrated in Fig. **10**. In addition, correlation functions such as temporal correlation, spatial correlation, and isosceles correlation are examined simultaneously. The authors in [34] investigate the packet inter-reception (PIR) and packet inter-loss (PIL) time distributions. The link between channel precondition and packet loss is explored using the distribution, and LoS and NLoS channel conditions are found to have significant effects on V2V communication. In [61] Karedal *et al.* focused on application-level responsibility, where the T-window responsibility was planned to learn about the measurement data to gauge the community functionality of successfully sending at least once during the tolerance time window T, where parameter T is utility related.

In addition to dependability, the V2V discussion in IoV considers network performance such as output, affiliation duration, and time overhead of connection establishment, among other things [62]. Cheng *et al.* [25] used measurement statistics to choose the offloading capabilities of a variety of different strategies to reduce the cell load. The size information can also be used to examine IoV channel properties, including route loss, Doppler spectrum, and coherence time. They employed the positioning system to enable large-scale measurement and gather vast information to emulate such silent channel qualities. The packet measurement and modulation approach impacts the re-transmission threat and communication variability, according to the explanation in [63]. Furthermore, the results of channel size show that the widely used 802.11p standard is well-suited to account for Doppler and delay spreads in transport channels.

Simulating real-world processes is an effective verification strategy in researching and designing communication protocols to prevent losing time and money. A good IoV simulation environment is needed to obtain reliable results. For IoV protocol style analysis and development, the IoV statistics are employed to provide a suitable transport excellent model and V2X channel model. For example, to reproduce the high-quality mannequin in IoV, which defines the design of transportation networks [23], GPS data representing car movement are duplicated. The authors in [64] use realistic mobility models built using trace statistics from automobiles in California, Shanghai, and San Francisco. Akhtar *et al.* [65] applied suggestion records to a microscopic first-rate mannequin developed by the Simulation of Urban Satisfactory (SUMO) and showed that the accuracy of the mannequin can be increased. Zhu *et al.* [66] employed trace data to determine the inter-contact time of any two cars to follow the tail distribution in the large model.

Celes *et al.* employed vehicle trajectory records to calculate route hops in trace facts, which can subsequently be entered into [64]. Channel models have been employed in IoV analysis as a prerequisite to communication protocol design, such as log-normal shadowing mannequins [65] and geometry-based stochastic models [63]. By comparing massive trace records with the theoretical output, the parameters of the channel models may be altered in various contexts, such as metropolitan regions suburban and rural areas [67]. Big data may also be utilized to determine the impact of antenna sample variations on passing vehicles. In a V2V propagation scenario, L. Cheng *et al.* [68] adopted a speed-separation design to estimate the coherence time and channel Doppler unfolds. They demonstrated that a continuous, and 0 Doppler spectrum could be found using large hint data in a typical visitor's situation.

VII. EMERGING TECHNOLOGY-BASED VANET CHALLENGES

Emerging VANET technologies in terms of its services are identified and outlined in Table **4**.

- **Intermittent connectivity:** It is vital to control and manage network connections between cars and networks. Due to significant vehicle mobility or substantial packet loss, intermittent connections in vehicular networks must be terminated.
- **High mobility and location awareness:** Future VANETs will need a high degree of vehicle mobility and location data. In the case of an emergency, each vehicle should be aware of the locations of other automobiles in the network.
- **Heterogeneous vehicle management:** A significant number of heterogeneous smart cars will be available in the future. Future VANETs will have to handle a wide range of vehicles with intermittent connectivity.
- **Security:** Data, information, and the locations of users are never guaranteed to be secure. Users should be able to choose what information is shared and what information is kept private while automobiles connect to inside networks. Personal data can be evaluated locally instead of being sent to the cloud for analysis, thereby safeguarding privacy. We compare different available technologies in terms of their methods, security standards, and overall running cost in Table **5** while focusing on different technology standards.
- **Network intelligence support:** VANETs in the future will confront several challenges, including the need to increase network intelligence. Cars will be outfitted with a wide range of sensors in future VANETs, and the edge cloud will store and preprocess data before sending the data to other parts of the network, such as standard cloud servers.

TABLE 4. VANET services for emergening technologies.

Services	IoV	Big Data	SIoT	Fog	MEC	SDN
Application and Services	✓	✓	✓	✓	✓	✓
Transmission and Strategy	✓	✓	✓	✓	✓	✓
Required Information	✓	×	✓	×	✓	✓
Geo-Map Information	✓	×	✓	×	✓	✓
Routing Protocol	✓	×	✓	✓	✓	✓
High Security Sensitivity	✓	✓	×	✓	×	✓
Required High Reliability	✓	✓	✓	✓	✓	✓
Lower Utilization Cost	×	×	×	✓	×	✓
Reliable User Experience	✓	✓	✓	✓	✓	×
Lower Computational Power	×	×	✓	×	×	✓

TABLE 5. A comparative study in terms of Security and cost in different available technologies.

Reference	Focused Method	Technologies	Security	Cost
[4], [73]	Trust authentication using BAN logic; AI powered block-chain protocol	IoV	High	High
[74], [75]	Data security and privacy; big-data analytics in healthcare	Big Data	High	High
[22], [76]	Security and privacy for SIoT; SIoT integrated with OAT	SIoT	High	High
[2], [15]	Comparison among Fog computing, cloudlet and mobile edge computing; Fog computing based ITS	Cloudlets	Low	High
[2], [15]	Comparison among Fog computing, cloudlet and mobile edge computing; Fog computing based ITS	Fog	Medium	Low
[2], [15]	Comparison among Fog computing, cloudlet and mobile edge computing; Fog computing based ITS	MEC	High	High
[1], [39]	SDN security and network issues	SDN	High	Low

- **Blockchain technology:** Bitcoin is based on the blockchain [69]. A blockchain is a publicly viewable database that strings the benefits, services, current works, security, and use cases for SDN-VANET into a sequence of blocks in the block headers using cryptographic hashing. These blocks include multiple-user transactions, and each new block is assigned to a different miner. The miner may be selected using the unanimity approach. Only a few designated parties are required to maintain a flawless blockchain [70].

Users may keep track of their transactions using this method.

- **5G-enabled vehicular network:** V2X communication is well-suited to cellular technology. In response to growing problems and expectations, projects and industries have incorporated 5G technology for in-vehicle networks [71], primarily to improve performance [72]. First, vehicles can swiftly join or leave a network due to their high mobility and uneven distribution, and vehicle links are often joined and detached; as a result, timely network topology updates are critical to 5G-operations. The 5G or higher VANET latency standards exacerbate these problems by requiring a more consistent connection quality. When high-density vehicles interface directly with the BS or RSU during peak hours, a substantial amount of concurrent V2I communication can occur in emerging technologies for 5G-enabled vehicular networks. 5G-enabled car network technology is currently in development. Due to extremely high signaling overhead, the chance of an outage is considerable. Because of their diversified and inflexible cellular network design, multiple access networks and vendor-specific devices have created another hurdle to 5G-VANET. 5G is projected to employ a heterogeneous network (HetNet) design because of the unavoidable network diversification caused by high data rates and the combined usage of several wireless technologies. Moreover, while 5G technology is built to achieve "high capacity, huge bandwidth, large connections, low latency, and low power consumption," vendor-specific hardware and protocols make dynamically adjusting network operations challenging and costly for operators as future 5G networks become more sophisticated. We studied the required services that are currently being used in different emerging technologies. In addition, we present a summary in terms of methods used while implementing VANET infrastructure in Table **6**.

VIII. OPEN ISSUES FOR FUTURE VANETs

For future VANET development, several problems and issues must be addressed as follows:

- **Low-latency and real-time application:** For real-time applications of future VANETs, reduced latency will be crucial. Future VANETs should offer real-time, low-latency applications such as security warnings.
- **High bandwidth:** High-definition video streaming, as well as other forms of entertainment and convenience, will be in high demand in the future. In addition, traffic apps like 3D maps and navigation systems require frequent automatic updates.
- **Connectivity:** Reliable synchronization between linked automobiles will be necessary to satisfy the high communication demands of future VANETs. Vehicles that are connected or self-driving should maintain a constant and efficient connection with fog devices, and they should be able to prevent communication channel propagation problems.
- **Deployment of Network Elements:** When a network has a sufficient number of nodes, its performance improves on a large scale. Because network equipment deployment is expensive, it is vital to have the correct number of network parts up and running as quickly as feasible. The greatest difficulty is choosing a suitable location that will maximize the effectiveness of vehicle networks [96]. Costs must also be kept to a minimum, and edge servers and SRSUs should be placed where available resources can be efficiently managed. More servers should be placed in congested areas because of the various traffic distribution in the urban environment. The reception time of servers sending messages to other nodes can be lowered considerably by connecting the infrastructure through fewer hops. As a result, an ideal model must be established to identify the smallest number of edge servers and SRSUs that must be installed while retaining service quality [97].
- **Forwarded Routing and Switching Technologies:** Vehicles are always moving and must make quick decisions regarding their next step. As a result, depending on traffic and public transit data, predicting which exact car would receive services from which base station or edge server is difficult. Despite several methodologies being used to address this issue, it remains an open topic. When a vehicle switches from one edge server to another, the services it previously used are transmitted to the new edge server [98].
- **Utilized Mobility Models:** In the past, sensor network models assumed that the environment remained static. Ad hoc networks, on the other hand, are designed for users with limited mobility due to laptops and mobile devices. By contrast, mobility is a given for vehicle networks. Vehicle mobility patterns are closely connected. Each automobile on the road has a constantly changing set of neighbors, some of whom it has never met before and is extremely unlikely to meet again. Because of the constantly changing nature of vehicle dynamics, reputation-based solutions may be ineffective. Rating different automobiles based on the reliability of their reports is unlikely to be advantageous; that is, any particular vehicle may not be able to gather sufficient information from another vehicle to make an educated decision about that vehicle. We could not test protocols that require sender-receiver touch since any two automobiles are in communication range for only a few seconds. To provide data on actual vehicular behavior, such as vehicle speed, reputation prediction, and dispersion in both space and time, a more complex mobility model is necessary [99].
- **Content Caching:** Content caching techniques that may be employed in VEC include prefetching and cooperative caching. The cache may also contain information the vehicles have not requested but may obtain through

TABLE 6. A comparative study of focused methods among available technologies.

Reference	Focused Method
[8], [14]	– SDN supporting controller architecture – Fog computing with conventional VANET and safety messages in VANETs
[13], [69]	– Operational SDN testbeds – Fog computing with conventional VANET
[12], [77]	– DSRC and C2C-CC integrated with IoV – BDA with bibliometric methods in different functional management domains
[77], [78]	– Spark and SQL style processing architecture – Paradigm of SioT
[21], [26]	– SIoT-RIMM – Computation-Intensive Graph Jobs Over Vehicular Clouds
[24], [79]	– Big Data integrated with blockchain – IoV routing protocol
[80], [81]	– Anticipatory Mobility Management – Content sharing-oriented matching algorithm
[82], [83]	– Geo-Located Mobile Social Media – Architecture for SioT
[84], [85]	– Big data processing in a real-time/near real-time – IoV for real-time traffic data analysis
[16], [86]	– Strategies towards cloud computing – Big Data and HCI
[18], [87]	– Offloading Social Media Services in Industrial Cognitive IoV – IoV with HCI
[88], [89]	– Big Data-Driven TV Ecosystem – Dynamic adaptation of SIoV
[16], [90]	– WSAN in IoT – Load balancing strategy
[91], [92]	– LoRa for future IoV – Service-Oriented SIoT

their wireless connection. It may be advantageous for automobiles to store and send nonrequested items (e.g., alarms generated in case of trouble). Furthermore, caching techniques that allow for the most efficient temporal and spatial scope of vehicle material still have gaps [100]. The cache can be maintained by caching-in and caching-out items outside their geographic scope (for example, emergency signals on the other side of the country but inside the relevant region) and old content (e.g., traffic congestion information on a highway from an hour in the past.).

- **Security Endurance:** Vehicle networks' flexibility and lack of rigidity have generated worries about data security and privacy, with authentication security being the most challenging issue. There is a risk of compromised security and privacy since nodes act as access points to hybrid clouds, which contain both edge nodes and the central cloud. A hacker with access to any edge node can send messages and instructions that are not permitted. Furthermore, if the network is compromised, users' privacy may be threatened since hackers may gain access to their personal information. However, because of the rapid proliferation of vehicular edge networks, various security vulnerabilities are expected. More dynamic frameworks are required to correctly encrypt data, to ensure that security and privacy are not jeopardized, thereby making edge computing safer [96].
- **Smart Vehicular Network Layer:** Smart cars require optimal connectivity as they progress toward self-driving capabilities. As a result, the most important aspect in the development of smart cities and intelligent transportation systems is the expansion of vehicle networks [101]. Automotive networks are expected to support high-end applications, including enhanced

TABLE 7. Comparative study of IoV, BigData, SIoT, Fog computing, and SDN in terms of VANET key features (Part-I).

Ref.	Key features	IoV	Big Data	SIoT	Fog	SDN
[8], [14], [77],	Proposed or introduced by	N/A	In 2005, Roger Mougalas	N/A	Cisco in Aug. 2012	Martin Casado
[8], [13], [69]	John Mashey, the chief scientist at Silicon Graphics in the 1990s.	SIoT Organization	Cisco, Princeton, Microsoft, Intel, Dell	Open Networking Foundation (ONF)	N/A	N/A
[8], [13], [16]	Industry organizations	N/A	N/A	N/A	OpenFog Consortium	Open Networking Foundation (ONF), Cisco
[12], [13], [69]	Inspiration	To support vehicular communications, (DSRC) and (C2C-CC)	Predictive analytics, User behavior analytics, or certain other advanced data analytics	To solve the extremely high complexity of the IoT environments	MEC as stepping stone towards 5G mobile networks	Server virtualization, and the advent of cloud services
[13], [78], [79]	Architecture framework	Distributed Layer architecture	Yes, Hadoop and Spark	Object and gateway	Yes	Yes, SDN Application, controller, Datapath, Control to Data Panel Interface
[21], [26], [78]	Geo-distributed	Yes	Yes	Yes	Yes	Yes
[13], [24], [79]	Network AS	Centralized, decentralized, and hybrid panels	Centralized and Decentralized	Decentralized	Decentralized	Centralized and Decentralized
[13], [80], [81]	Low latency or jitter	Yes	Yes	Yes	Yes	Yes
[6], [82], [83]	Geo-mobility support for applications on device	Yes	Yes	Yes	Yes	Yes
[84], [83], [93]	Near real-time interaction	Yes	Yes	Yes	Yes	Yes

traffic efficiency, autonomous driving, and continuous Internet access. Autonomous vehicles are gaining popularity around the world, leading to a recent revolution in the automobile industry. However, despite having developed fully autonomous automobiles, significant challenges remain, including security, dependability, and privacy. This is especially true in the case of self-driving cars, which are subject to a range of security threats; for example, a single virus attack might cause a plethora of problems [102].

- **Augmented Reality:** AR is a multimedia application in development that seamlessly blends real-world scenes into virtual scenes and superimposes virtual scenes over real-world scenes to augment standard real-image information. This technology can assist drivers in being more aware of nearby automobiles and pedestrians. In addition, the heads-up display decreases driver distractions [103], thereby improving driving safety. The usage of augmented reality (AR) content with a heads-up-display (HUD) navigation system has been examined. Similarly, the safety and convenience of a HUD-based navigation system have been explored. Recently, a walk navigation program was developed using AR technology to operate an automobile navigation system utilizing a camera and GPS. This technique is helpful since it directs the car down a virtual path. Without endangering safety, the driver can utilize real-time navigation to monitor his or her driving circumstances [104].
- **Vehicular Edge Computing (VEC):** This type of networking relies on a logically centralized network control layer. It helps in constructing a dependable resource management and traffic control system. An SDN-oriented network provides flexible

TABLE 8. Comparative study of IoV, BigData, SIoT, Fog computing, and SDN in terms of VANET key features (Part-II).

Ref.	Key features	IoV	Big Data	SIoT	Fog	SDN
[13], [16], [83]	Emphasis on online data analytics	interaction with cloud	Yes	Yes	Yes	Yes
[16], [18], [87]	Edge server location	Roadside unit	Cloud and flexible location	MEC server collocated with BS	Flexible b/w end device and cloud	Internet Exchange Point (IxPs)
[14], [88], [89]	Dynamic broadcasting range depending on the message type	Yes	Yes	Yes	Yes	Yes
[83], [90], [93]	Location awareness	Suffers with location awareness	Yes	Yes	Yes	Yes
[6], [13], [83]	Mobility support	Yes	Yes	Yes	Yes	Yes
[14], [89], [94]	Channel Bandwidth	Yes	Dynamic	Yes	75 MHz for 802.11p	Dynamic
[14], [91], [94]	Capacity	Yes	Dynamic	Dynamic	6 Mbps for 802.11p	Dynamic
[89], [91], [95]	Scalability	Yes	Dynamic	Dynamic	High	Dynamic
[8], [13], [92]	Run experimental test bed	LoRa PHY Link with ICMPv6 protocol	N/A	N/A	Yes, at Princeton	Yes, at Berkeley and National University of Singapore

programmability. [105], and network knowledge. For services that are sensitive and require real-time analysis, edge/fog computing paired with SDN can reduce latency problems. This link can also aid in the effective administration and delivery of network services [106].

- **Fog-Edge Resource Allocation Network (FeRAN):** An edge server must have sufficient resources to transfer services from a source node to a destination node. When a substantial number of user requests occur simultaneously, an edge node's collection of resources is insufficient, and it may become overloaded; this results in degraded performance, for example, during peak traffic. One study concentrated on management methods at each edge node (fog node) [11]., to enable FeRANs to implement channel resource management. The service quality has improved, in terms of real-time vehicular services, fog resource reserves, and reallocation. Our method enhances the on-hop probability for real-time vehicular services, even when the fog resource is loaded [107].

We investigate different types of key features in terms of VANET technologies in Tables **7** and **8** while identifying the attributes that face challenges during deployment periods. Moreover, the types of obstacles and problems that need to be addressed for future development purposes are depicted.

IX. CONCLUSION

The VANET is a needed feature for intelligent automobiles. However, significant improvements, changes, and technology developments have transferred VANET communication patterns away from traditional means. In these current challenging times to keep pace with technology trends, VANETs must facilitate evolving and emerging pattern prototypes and issues. For future VANETs and problems related to ITS (intelligent transport systems), utilizing emerging technologies is a suitable option for VANET research and legacy continuity. This path also represents a new direction for young researchers to improve VANET communication patterns, ethical accessions, high performance data delivery, and much more. In this review paper, we have introduced the most recent technologies for VANET upgrading and developments to overcome issues in future VANET research. We have introduced VANET throug the perspective of SDN, fog computing, SIoT, IoV aerial extension usage, IoV aware big data intelligence, big data protocol intelligence, big data application-aware strategies, and big data reliability managements for V2V, V2X, and MEC mechanisms. These perspectives of future VANET research, upgrading, and developments represent promising outputs. This paper presents an organization chart depicting the emerging VANET platforms. Additionally, this paper considers future VANET research and developments in terms of emerging technologies, obstacles, issues alleviation, and on-demand technology. Finally, this paper supports the combination of VANET and evolving technologies for future VANET researcher and technology entrepreneurs.

DECLARATION OF COMPETING INTEREST/CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

[1] W. He, G. Yan, and L. D. Xu, "Developing vehicular data cloud services in the IoT environment," *IEEE Trans. Ind. Inform.*, vol. 10, no. 2, pp. 1587–1595, May 2014.

[2] T. S. J. Darwish and K. A. Bakar, "Fog based intelligent transportation big data analytics in the internet of vehicles environment: Motivations, architecture, challenges, and critical issues," *IEEE Access*, vol. 6, pp. 15679–15701, 2018.

[3] R. I. Meneguette, "A vehicular cloud-based framework for the intelligent transport management of big cities," *Int. J. Distrib. Sensor Netw.*, vol. 12, no. 5, May 2016, Art. no. 8198597.

[4] Y. Liu, Y. Wang, and G. Chang, "Efficient privacy-preserving dual authentication and key agreement scheme for secure V2V communications in an IoV paradigm," *IEEE Trans. Intell. Transp. Syst.*, vol. 18, no. 10, pp. 2740–2749, Oct. 2017.

[5] O. S. Al-Heety, Z. Zakaria, M. Ismail, M. M. Shakir, S. Alani, and H. Alsariera, "A comprehensive survey: Benefits, services, recent works, challenges, security, and use cases for SDN-VANET," *IEEE Access*, vol. 8, pp. 91028–91047, 2020.

[6] M. Wang, J. Wu, G. Li, J. Li, Q. Li, and S. Wang, "Toward mobility support for information-centric IoV in smart city using fog computing," in *Proc. IEEE Int. Conf. Smart Energy Grid Eng. (SEGE)*, Aug. 2017, pp. 357–361.

[7] R. Hussain, J. Son, H. Eun, S. Kim, and H. Oh, "Rethinking vehicular communications: Merging VANET with cloud computing," in *Proc. 4th IEEE Int. Conf. Cloud Comput. Technol. Sci.*, Dec. 2012, pp. 606–609.

[8] R. Shrestha, R. Bajracharya, and S. Y. Nam, "Challenges of future VANET and cloud-based approaches," *Wireless Commun. Mobile Comput.*, vol. 2018, pp. 1–15, May 2018.

[9] S. Olariu, T. Hristov, and G. Yan, "The next paradigm shift: From vehicular networks to vehicular clouds," in *Mobile Ad Hoc Networking, Cutting Edge Directions*. Hoboken, NJ, USA: Wiley, 2013, pp. 645–700.

[10] S. Islam and J.-C. Grégoire, "Giving users an edge: A flexible cloud model and its application for multimedia," *Future Gener. Comput. Syst.*, vol. 28, no. 6, pp. 823–832, Jun. 2012.

[11] M. Whaiduzzaman, M. Sookhak, A. Gani, and R. Buyya, "A survey on vehicular cloud computing," *J. Netw. Comput. Appl.*, vol. 40, pp. 325–344, Nov. 2013.

[12] X. Shen, R. Fantacci, and S. Chen, "Internet of vehicles [scanning the issue]," *Proc. IEEE*, vol. 108, no. 2, pp. 242–245, Feb. 2020.

[13] S. S R, J. Mikovic, P. G. Kannan, C. Mun Choon, and K. Sklower, "Enabling SDN experimentation in network testbeds," in *Proc. ACM Int. Workshop Secur. Softw. Defined Netw. Netw. Function Virtualization*, Mar. 2017, pp. 7–12.

[14] S. Ahmad and A. H. Mir, "Scalability, consistency, reliability and security in SDN controllers: A survey of diverse SDN controllers," *J. Netw. Syst. Manage.*, vol. 29, no. 1, pp. 1–59, Jan. 2021.

[15] K. Dolui and S. K. Datta, "Comparison of edge computing implementations: Fog computing, cloudlet and mobile edge computing," in *Proc. Global Internet Things Summit (GIoTS)*, Jun. 2017, pp. 1–6.

[16] X. Xu, B. Shen, X. Yin, M. R. Khosravi, H. Wu, L. Qi, and S. Wan, "Edge server quantification and placement for offloading social media services in industrial cognitive IoV," *IEEE Trans. Ind. Informat.*, vol. 17, no. 4, pp. 2910–2918, Apr. 2021.

[17] M. Satyanarayanan, G. Lewis, E. Morris, S. Simanta, J. Boleng, and K. Ha, "The role of cloudlets in hostile environments," *IEEE Pervasive Comput.*, vol. 12, no. 4, pp. 40–49, Oct. 2013.

[18] C.-H. Wang, J.-J. Kuo, D.-N. Yang, and W.-T. Chen, "Collaborative social Internet of Things in mobile edge networks," *IEEE Internet Things J.*, vol. 7, no. 12, pp. 11473–11491, Dec. 2020.

[19] M. Biswas and M. Whaiduzzaman, "Efficient mobile cloud computing through computation offloading," *Int. J. Adv. Technol.*, vol. 10, no. 2, p. 32, 2018.

[20] M. Whaiduzzaman, M. J. N. Mahi, A. Barros, M. I. Khalil, C. Fidge, and R. Buyya, "BFIM: Performance measurement of a blockchain based hierarchical tree layered fog-IoT microservice architecture," *IEEE Access*, vol. 9, pp. 106655–106674, 2021.

[21] M. Hamza, H. Hu, M. A. Akbar, F. Mehmood, Y. Hussain, and A. M. Baddour, "SIOT-RIMM: Towards secure IoT-requirement implementation maturity model," in *Proc. Eval. Assessment Softw. Eng.*, Apr. 2020, pp. 463–468.

[22] R. Faqihi, J. Ramakrishnan, and D. Mavaluru, "An evolutionary study on the threats, trust, security, and challenges in SIoT (social Internet of Things)," *Mater. Today, Proc.*, Oct. 2020.

[23] C. M. Martinez, M. Heucke, B. Gao, D. Cao, and F.-Y. Wang, "Driving style recognition for intelligent vehicle control and advanced driver assistance: A survey," *IEEE Trans. Intell. Transp. Syst.*, vol. 19, no. 3, pp. 666–676, Mar. 2018.

[24] H. Yu, Z. Yang, and R. O. Sinnott, "Decentralized big data auditing for smart city environments leveraging blockchain technology," *IEEE Access*, vol. 7, pp. 6288–6296, 2019.

[25] N. Cheng, N. Lu, N. Zhang, X. S. Shen, and J. W. Mark, "Vehicular WiFi offloading: Challenges and solutions," *Veh. Commun.*, vol. 1, no. 1, pp. 13–21, 2014.

[26] M. LiWang, S. Hosseinalipour, Z. Gao, Y. Tang, L. Huang, and H. Dai, "Allocation of computation-intensive graph jobs over vehicular clouds in IoV," *IEEE Internet Things J.*, vol. 7, no. 1, pp. 311–324, Jan. 2020.

[27] H. Farhady, L. HyunYong, and N. Akihiro, "Software-defined networking: A survey," *Comput. Netw.*, vol. 81, pp. 79–95, Apr. 2015.

[28] P. Lin, J. Bi, and Y. Wang, "East-west bridge for SDN network peering," in *Frontiers in Internet Technologies*. Cham, Switzerland: Springer, 2013, pp. 170–181.

[29] W. Rafique, L. Qi, I. Yaqoob, M. Imran, R. U. Rasool, and W. Dou, "Complementing IoT services through software defined networking and edge computing: A comprehensive survey," *IEEE Commun. Surveys Tuts.*, vol. 22, no. 3, pp. 1761–1804, 3rd Quart., 2020.

[30] W. Quan, Y. Liu, H. Zhang, and S. Yu, "Enhancing crowd collaborations for software defined vehicular networks," *IEEE Commun. Mag.*, vol. 55, no. 8, pp. 80–86, Aug. 2017.

[31] S. Mostafi, F. Khan, A. Chakrabarty, D. Y. Suh, and M. J. Piran, "An algorithm for mapping a traffic domain into a complex network: A social Internet of Things approach," *IEEE Access*, vol. 7, pp. 40925–40940, 2019.

[32] M. M. Rad, A. M. Rahmani, A. Sahafi, and N. N. Qader, "Social Internet of Things: Vision, challenges, and trends," *Hum.-Centric Comput. Inf. Sci.*, vol. 10, no. 1, pp. 1–40, Dec. 2020.

[33] J. Qin, H. Zhu, Y. Zhu, L. Lu, G. Xue, and M. Li, "POST: Exploiting dynamic sociality for mobile advertising in vehicular networks," *IEEE Trans. Parallel Distrib. Syst.*, vol. 27, no. 6, pp. 1770–1782, Jun. 2016.

[34] F. Lv, H. Zhu, H. Xue, Y. Zhu, S. Chang, M. Dong, and M. Li, "An empirical study on urban IEEE 802.11p vehicle-to-vehicle communication," in *Proc. 13th Annu. IEEE Int. Conf. Sens., Commun., Netw. (SECON)*, Jun. 2016, pp. 1–9.

[35] H. Zhou, W. Xu, J. Chen, and W. Wang, "Evolutionary V2X technologies toward the internet of vehicles: Challenges and opportunities," *Proc. IEEE*, vol. 108, no. 2, pp. 308–323, Feb. 2020.

[36] W. Xu, H. A. Omar, W. Zhuang, and X. S. Shen, "Delay analysis of in-vehicle internet access via on-road WiFi access points," *IEEE Access*, vol. 5, pp. 2736–2746, 2017.

[37] N. Aung, W. Zhang, K. Sultan, S. Dhelim, and Y. Ai, "Dynamic traffic congestion pricing and electric vehicle charging management system for the internet of vehicles in smart cities," *Digit. Commun. Netw.*, vol. 7, no. 4, pp. 492–504, Nov. 2021.

[38] W. Shi, H. Zhou, J. Li, W. Xu, N. Zhang, and X. Shen, "Drone assisted vehicular networks: Architecture, challenges and opportunities," *IEEE Netw.*, vol. 32, no. 3, pp. 130–137, May 2017.

[39] N. Zhang, S. Zhang, P. Yang, O. Alhussein, W. Zhuang, and X. Shen, "Software defined space-air-ground integrated vehicular networks: Challenges and solutions," *IEEE Commun. Mag.*, vol. 55, no. 7, pp. 101–109, Jul. 2017.

[40] A. Mukhtar, L. Xia, and T. B. Tang, "Vehicle detection techniques for collision avoidance systems: A review," *IEEE Trans. Intell. Transp. Syst.*, vol. 16, no. 5, pp. 2318–2338, May 2015.

[41] E. Mack, "Meet Google's project loon: Balloon-powered net access," *CNET. Retrieved*, vol. 15, 2013.

[42] I. Bor-Yaliniz and H. Yanikomeroglu, "The new frontier in RAN heterogeneity: Multi-tier drone-cells," *IEEE Commun. Mag.*, vol. 54, no. 11, pp. 48–55, Nov. 2016.

[43] S. Roy, A. R. Shovon, and M. Whaiduzzaman, "Combined approach of tokenization and mining to secure and optimize big data in cloud storage," in *Proc. IEEE Region Humanitarian Technol. Conf. (R10-HTC)*, Dec. 2017, pp. 83–88.

[44] N. Alam, A. T. Balaei, and A. G. Dempster, "Relative positioning enhancement in VANETs: A tight integration approach," *IEEE Trans. Intell. Transp. Syst.*, vol. 14, no. 1, pp. 47–55, Mar. 2013.

[45] A. K. Widiawan and R. Tafazolli, "High altitude platform station (HAPS): A review of new infrastructure development for future wireless communications," *Wireless Pers. Commun.*, vol. 42, no. 3, pp. 387–404, Jun. 2007.

[46] M. T. Rahman, M. J. N. Mahi, M. Biswas, M. S. Kaiser, and S. Al Mamun, "Performance evaluation of a portable PABX system through developing new bandwidth optimization technique," in *Proc. Int. Conf. Electr. Eng. Inf. Commun. Technol. (ICEEICT)*, May 2015, pp. 1–5.

[47] M. Mahi, J. Nayeen, M. Biswas, O. Kushum, M. Whaiduzzaman, and S. Al Mamun, "A new unified communication approach to comply bandwidth optimization technique using dynamic channel allocation," *Int. J. Comput. Netw. Technol.*, vol. 6, no. 1, pp. 1–11, Jan. 2018.

[48] M. A. Islam, M. Biswas, M. J. N. Mahi, and M. Whaiduzzaman, "LBRP: A resilient energy harvesting noise aware routing protocol for under water sensor networks (UWSNS)," *Int. J. Found. Comput. Sci. Technol.*, vol. 8, nos. 4–5, Sep. 2018.

[49] O. S. Oubbati, A. Lakas, F. Zhou, M. Güneş, N. Lagraa, and M. B. Yagoubi, "Intelligent UAV-assisted routing protocol for urban VANETs," *Comput. Commun.*, vol. 107, pp. 93–111, Jul. 2017.

[50] M. R. Hossain, M. Whaiduzzaman, A. Barros, S. R. Tuly, M. J. N. Mahi, S. Roy, C. Fidge, and R. Buyya, "A scheduling-based dynamic fog computing framework for augmenting resource utilization," *Simul. Model. Pract. Theory*, vol. 111, Sep. 2021, Art. no. 102336.

[51] M. J. N. Mahi, K. M. Hossain, M. Biswas, and M. Whaiduzzaman, "SENTRAC: A novel real time sentiment analysis approach through Twitter cloud environment," in *Advances in Electrical and Computer Technologies*. Cham, Switzerland: Springer, 2020, pp. 21–32.

[52] M. Biswas, M. H. Tania, M. S. Kaiser, R. Kabir, M. Mahmud, and A. A. Kemal, "ACCU3RATE: A mobile health application rating scale based on user reviews," *PLoS ONE*, vol. 16, no. 12, Dec. 2021, Art. no. e0258050.

[53] S. Bharati, H. A. Omar, and W. Zhuang, "Enhancing transmission collision detection for distributed TDMA in vehicular networks," *ACM Trans. Multimedia Comput., Commun., Appl.*, vol. 13, no. 3s, pp. 1–21, Aug. 2017.

[54] F. Bai and H. Krishnan, "Reliability analysis of DSRC wireless communication for vehicle safety applications," in *Proc. IEEE Intell. Transp. Syst. Conf.*, Sep. 2006, pp. 355–362.

[55] N. Wisitpongphan, O. K. Tonguz, J. S. Parikh, P. Mudalige, F. Bai, and V. Sadekar, "Broadcast storm mitigation techniques in vehicular ad hoc networks," *IEEE Wireless Commun.*, vol. 14, no. 6, pp. 84–94, Dec. 2007.

[56] M. Chaqfeh, A. Lakas, and I. Jawhar, "A survey on data dissemination in vehicular ad hoc networks," *Veh. Commun.*, vol. 1, no. 4, pp. 214–225, Oct. 2014.

[57] R. Hossen, M. Whaiduzzaman, M. N. Uddin, M. J. Islam, N. Faruqui, A. Barros, M. Sookhak, and M. J. N. Mahi, "BDPS: An efficient spark-based big data processing scheme for cloud fog-IoT orchestration," *Information*, vol. 12, no. 12, p. 517, Dec. 2021.

[58] M. Whaiduzzaman, N. Farjana, A. Barros, M. Mahi, J. Nayeen, M. Satu, S. Roy, and C. Fidge, "HIBAF: A data security scheme for fog computing," *J. High Speed Netw.*, vol. 27, no. 4, pp. 381–402, Oct. 2021.

[59] G. Y. Chang, J.-P. Sheu, T.-Y. Lin, and K.-Y. Hsieh, "Cache-based routing for vehicular ad hoc networks in city environments," in *Proc. IEEE Wireless Commun. Netw. Conf.*, Apr. 2010, pp. 1–6.

[60] F. Bai, D. D. Stancil, and H. Krishnan, "Toward understanding characteristics of dedicated short range communications (DSRC) from a perspective of vehicular network engineers," in *Proc. 16th Annu. Int. Conf. Mobile Comput. Netw. (MobiCom)*, 2010, pp. 329–340.

[61] J. Karedal, N. Czink, A. Paier, F. Tufvesson, and A. F. Molisch, "Path loss modeling for vehicle-to-vehicle communications," *IEEE Trans. Veh. Technol.*, vol. 60, no. 1, pp. 323–328, Jan. 2011.

[62] J. Eriksson, H. Balakrishnan, and S. Madden, "CaberNet: Vehicular content delivery using WiFi," in *Proc. 14th ACM Int. Conf. Mobile Comput. Netw. (MobiCom)*, 2008, pp. 199–210.

[63] C. F. Mecklenbrauker, A. F. Molisch, J. Karedal, F. Tufvesson, A. Paier, L. Bernadó, T. Zemen, O. Klemp, and N. Czink, "Vehicular channel characterization and its implications for wireless system design and performance," *Proc. IEEE*, vol. 99, no. 7, pp. 1189–1212, Jul. 2011.

[64] C. Celes, F. A. Silva, A. Boukerche, R. M. de Castro Andrade, and A. A. F. Loureiro, "Improving VANET simulation with calibrated vehicular mobility traces," *IEEE Trans. Mobile Comput.*, vol. 16, no. 12, pp. 3376–3389, Dec. 2017.

[65] N. Akhtar, S. C. Ergen, and O. Ozkasap, "Vehicle mobility and communication channel models for realistic and efficient highway VANET simulation," *IEEE Trans. Veh. Technol.*, vol. 64, no. 1, pp. 248–262, Jan. 2015.

[66] H. Zhu, M. Li, L. Fu, G. Xue, Y. Zhu, and L. M. Ni, "Impact of traffic influxes: Revealing exponential intercontact time in urban VANETs," *IEEE Trans. Parallel Distrib. Syst.*, vol. 22, no. 8, pp. 1258–1266, Aug. 2011.

[67] O. Renaudin, V.-M. Kolmonen, P. Vainikainen, and C. Oestges, "Non-stationary narrowband MIMO inter-vehicle channel characterization in the 5-GHz band," *IEEE Trans. Veh. Technol.*, vol. 59, no. 4, pp. 2007–2015, May 2010.

[68] L. Cheng, B. E. Henty, F. Bai, and D. D. Stancil, "Highway and rural propagation channel modeling for vehicle-to-vehicle communications at 5.9 GHz," in *Proc. IEEE Antennas Propag. Soc. Int. Symp.*, Jul. 2008, pp. 1–4.

[69] A. Iera, G. Morabito, and L. Atzori, "The social Internet of Things," in *Proc. IEEE Int. Conf. Cloud Eng.*, Jan. 2015, p. 1.

[70] Z. Ning, S. Sun, X. Wang, L. Guo, S. Guo, X. Hu, B. Hu, and R. Kwok, "Blockchain-enabled intelligent transportation systems: A distributed crowdsensing framework," *IEEE Trans. Mobile Comput.*, early access, May 13, 2021, doi: 10.1109/TMC.2021.3079984.

[71] Z. Ning, P. Dong, X. Wang, X. Hu, J. Liu, L. Guo, B. Hu, R. Y. K. Kwok, and V. C. M. Leung, "Partial computation offloading and adaptive task scheduling for 5G-enabled vehicular networks," *IEEE Trans. Mobile Comput.*, vol. 21, no. 4, pp. 1319–1333, Apr. 2022.

[72] Y. Yang and K. Hua, "Emerging technologies for 5G-enabled vehicular networks," *IEEE Access*, vol. 7, pp. 181117–181141, 2019.

[73] R. L. Kumar, Q.-V. Pham, F. Khan, M. J. Piran, and K. Dev, "Blockchain for securing aerial communications: Potentials, solutions, and research directions," *Phys. Commun.*, vol. 47, Aug. 2021, Art. no. 101390.

[74] S. Flesca, S. Greco, E. Masciari, and D. Saccá, *A Comprehensive Guide Through the Italian Database Research Over the last 25 Years*. Cham, Switzerland: Springer, 2018.

[75] D. W. Bates, S. Saria, L. Ohno-Machado, A. Shah, and G. Escobar, "Big data in health care: Using analytics to identify and manage high-risk and high-cost patients," *Health Affairs*, vol. 33, no. 7, pp. 1123–1131, Jul. 2014.

[76] V. Belackova, A. M. Salmon, M. Jauncey, and J. Bell, "Learning from the past, looking to the future—Is there a place for injectable opioid treatment among Australia's responses to opioid misuse?" *Int. J. Drug Policy*, vol. 71, pp. 164–168, Sep. 2019.

[77] S. Batistič and P. der Laken, "History, evolution and future of big data and analytics: A bibliometric analysis of its relationship to performance in organizations," *Brit. J. Manage.*, vol. 30, no. 2, pp. 229–251, Apr. 2019.

[78] S. Dolev, P. Florissi, E. Gudes, S. Sharma, and I. Singer, "A survey on geographically distributed big-data processing using MapReduce," *IEEE Trans. Big Data*, vol. 5, no. 1, pp. 60–80, Mar. 2019.

[79] L. Alouache, N. Nguyen, M. Aliouat, and R. Chelouah, "Survey on IoV routing protocols: Security and network architecture," *Int. J. Commun. Syst.*, vol. 32, no. 2, Jan. 2019, Art. no. e3849.

[80] C.-Y. Lin, K.-C. Chen, D. Wickramasuriya, S.-Y. Lien, and R. D. Gitlin, "Anticipatory mobility management by big data analytics for ultra-low latency mobile networking," in *Proc. IEEE Int. Conf. Commun. (ICC)*, May 2018, pp. 1–7.

[81] B. Wang, Y. Sun, S. Li, and Q. Cao, "Hierarchical matching with peer effect for low-latency and high-reliable caching in social IoT," *IEEE Internet Things J.*, vol. 6, no. 1, pp. 1193–1209, Feb. 2019.

[82] A. Cuzzocrea, G. Psaila, and M. Toccu, "An innovative framework for effectively and efficiently supporting big data analytics over geo-located mobile social media," in *Proc. 20th Int. Database Eng. Appl. Symp. (IDEAS)*, 2016, pp. 62–69.

[83] L. Atzori, A. Iera, G. Morabito, and M. Nitti, "The social Internet of Things (SIoT)—When social networks meet the Internet of Things: Concept, architecture and network characterization," *Comput. Netw.*, vol. 56, no. 16, pp. 3594–3608, Nov. 2012.

[84] X. Liu, N. Iftikhar, and X. Xie, "Survey of real-time processing systems for big data," in *Proc. 18th Int. Database Eng. Appl. Symp. (IDEAS)*, 2014, pp. 356–361.

[85] M. Nahri, A. Boulmakoul, L. Karim, and A. Lbath, "IoV distributed architecture for real-time traffic data analytics," *Proc. Comput. Sci.*, vol. 130, pp. 480–487, Jan. 2018.

[86] P. K. Paul and M. K. Ghose, "A novel educational proposal and strategies toward promoting cloud computing, big data, and human–computer interaction in engineering colleges and universities," in *Advances in Smart Grid and Renewable Energy*. Cham, Switzerland: Springer, 2018, pp. 93–102.

[87] Y. Cao, H. Song, O. Kaiwartya, B. Zhou, Y. Zhuang, Y. Cao, and X. Zhang, "Mobile edge computing for big-data-enabled electric vehicle charging," *IEEE Commun. Mag.*, vol. 56, no. 3, pp. 150–156, Mar. 2018.

[88] P. C. Murschetz and D. Prandner, "'Datafying' broadcasting: Exploring the role of big data and its implications for competing in a big data-driven tv ecosystem," in *Competitiveness in Emerging Markets*. Cham, Switzerland: Springer, 2018, pp. 55–71.

[89] K. M. Alam, M. Saini, and A. El Saddik, "Workload model based dynamic adaptation of social internet of vehicles," *Sensors*, vol. 15, no. 9, pp. 23262–23285, 2015.

[90] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli, "Fog computing and its role in the Internet of Things," in *Proc. 1st, Ed., MCC Workshop Mobile Cloud Comput. (MCC)*, 2012, pp. 13–16.

[91] M. S. Roopa and R. Buyya, "Trust management for service-oriented SIoT systems," in *Proc. 8th Int. Conf. Inf. Technology, IoT Smart City*, Dec. 2020, pp. 216–222.

[92] R. Sanchez-Iborra, J. Sanchez-Gomez, J. Santa, P. J. Fernandez, and A. F. Skarmeta, "IPv6 communications over Lora for future IoV services," in *Proc. IEEE 4th World Forum Internet Things (WF-IoT)*, Feb. 2018, pp. 92–97.

[93] X. He, Z. Ren, C. Shi, and J. Fang, "A novel load balancing strategy of software-defined cloud/fog networking in the internet of vehicles," *China Commun.*, vol. 13, pp. 140–149, Nov. 2016.

[94] F. Diniz Rossi, G. Da Cunha Rodrigues, R. N. Calheiros, and M. Da Silva Conterato, "Dynamic network bandwidth resizing for big data applications," in *Proc. IEEE 13th Int. Conf. e-Sci. (e-Sci.)*, Oct. 2017, pp. 423–431.

[95] R. Lovas, E. Nagy, and J. Kovács, "Cloud agnostic big data platform focusing on scalability and cost-efficiency," *Adv. Eng. Softw.*, vol. 125, pp. 167–177, Nov. 2018.

[96] S. Raza, S. Wang, M. Ahmed, and M. R. Anwar, "A survey on vehicular edge computing: Architecture, applications, technical issues, and future directions," *Wireless Commun. Mobile Comput.*, vol. 2019, pp. 1–19, Feb. 2019.

[97] Y. W. Law, M. Palaniswami, G. Kounga, and A. Lo, "WAKE: Key management scheme for wide-area measurement systems in smart grid," *IEEE Commun. Mag.*, vol. 51, no. 1, pp. 34–41, Jan. 2013.

[98] A. Mosenia and N. K. Jha, "A comprehensive study of security of isnternet-of-Things," *IEEE Trans. Emerg. Topics Comput.*, vol. 5, no. 4, pp. 586–602, Dec. 2017.

[99] K. Fan, J. Wang, X. Wang, H. Li, and Y. Yang, "Secure, efficient and revocable data sharing scheme for vehicular fogs," *Peer Peer Netw. Appl.*, vol. 11, no. 4, pp. 766–777, Jul. 2018.

[100] I. Stojmenovic and S. Wen, "The fog computing paradigm: Scenarios and security issues," in *Proc. Ann. Comput. Sci. Inf. Syst.*, Sep. 2014, pp. 1–8.

[101] H. Ye, G. Y. Li, and B.-H. F. Juang, "Deep reinforcement learning based resource allocation for V2V communications," *IEEE Trans. Veh. Technol.*, vol. 68, no. 4, pp. 3163–3173, Apr. 2019.

[102] H. Peng, L. Liang, X. Shen, and G. Y. Li, "Vehicular communications: A network layer perspective," *IEEE Trans. Veh. Technol.*, vol. 68, no. 2, pp. 1064–1078, Feb. 2019.

[103] S. Y. Cho, "Development of an IGVM integrated navigation system for vehicular lane-level guidance services," *J. Positioning, Navigat., Timing*, vol. 5, no. 3, pp. 119–129, Sep. 2016.

[104] H. S. Park, M. W. Park, K. H. Won, K. H. Kim, and S. K. Jung, "In-vehicle AR-HUD system to provide driving-safety information," *ETRI J.*, vol. 35, no. 6, pp. 1038–1047, Dec. 2013.

[105] S. Tomovic, K. Yoshigoe, I. Maljevic, and I. Radusinovic, "Software-defined fog network architecture for iot," *Springer Wireless Pers. Commun.*, vol. 92, no. 1, pp. 181–196, 2017.

[106] N. B. Truong, G. M. Lee, and Y. Ghamri-Doudane, "Software defined networking-based vehicular adhoc network with fog computing," in *Proc. IFIP/IEEE Int. Symp. Integr. Netw. Manage. (IM)*, May 2015, pp. 1202–1207.

[107] J. Li, C. Natalino, D. P. Van, L. Wosinska, and J. Chen, "Resource management in fog-enhanced radio access network to support real-time vehicular services," in *Proc. IEEE 1st Int. Conf. Fog Edge Comput. (ICFEC)*, May 2017, pp. 68–74.

MD. JULKAR NAYEEN MAHI received the B.Sc. and M.Sc. degrees from IIT, Jahangirnagar University, Bangladesh. He is currently a Lecturer with Daffodil International University, Bangladesh. His current research interests include distributed computer networks, embedded systems, the IoT, data mining, cloud computing, operating systems scheduling approach, network securities, and bio informatics.

SUDIPTO CHAKI received the B.Sc. degree in computer science and engineering from the Chittagong University of Engineering and Technology (CUET), Bangladesh. He is currently working as a full-time Lecturer with the Bangladesh University of Business and Technology (BUBT), Dhaka, Bangladesh. He has multiple publications in different research fields. His current research interests include machine learning (ML), computer vision (CV), digital image processing (DIP), computer networks (CN), and the Internet of Things (IoT). He received the Best Paper Award from the Conference on Trends in Electronics and Health Informatics (Springer).

SHAMIM AHMED received the B.S. and M.S. degrees in computer science and engineering from the Dhaka University of Engineering and Technology, Gazipur, Bangladesh, in 2010 and 2013, respectively. In 2011, he worked with the Department of Computer Science and Engineering, Dhaka International University, Dhaka, Bangladesh, as a Lecturer. In 2013, he joined the Department of Computer Science and Engineering, Bangladesh University of Business and Technology, Dhaka, as a Lecturer. Since 2015, he has been an Assistant Professor with the Department of Computer Science and Engineering, Bangladesh University of Business and Technology. His current research interests include artificial intelligence, computer vision, machine learning, deep learning, robotics, digital image processing, and systems and networking.

MILON BISWAS (Member, IEEE) received the degree in information technology from Jahangirnagar University, Bangladesh. He is currently working as an Assistant Professor and Coordinator of Diploma holders with the Department of Computer Science and Engineering, Bangladesh University of Business and Technology (BUBT). He is also an Adjunct Assistant Professor at the Bangladesh University of Professionals. He is passionate about learning fundamental algorithms, including data structures and artificial intelligence. He has multiple publications. His research interests include artificial intelligence, machine learning, health informatics, medical image processing, and data mining with applications. He was awarded the National Science and Technology Fellowship by ICT Ministry of People's Republic of Bangladesh for his research work during graduate studies.

M. SHAMIM KAISER (Senior Member, IEEE) received the bachelor's and master's degrees in applied physics, electronics and communication engineering from the University of Dhaka, Bangladesh, in 2002 and 2004, respectively, and the Ph.D. degree in telecommunication engineering from the Asian Institute of Technology, Thailand, in 2010. In 2005, he joined the Department of Electronics and Telecommunication Engineering, Daffodil International University, as a Lecturer. In 2010, he worked with the Department of Electrical and Electronic Engineering, Eastern University, Bangladesh, and the Department of Mathematics and Natural Sciences, BRAC University, Dhaka, as an Assistant Professor. Since 2011, he has been with the Institute of Information Technology, Jahangirnagar University, Dhaka, as an Assistant Professor, where he became an Associate Professor, in 2015, and a Full Professor, in 2019. He has authored more than 150 articles in different peer-reviewed journals and conferences. His current research interests include data analytics, machine learning, wireless networks and signal processing, cognitive radio networks, big data and cyber security, and renewable energy. He is a Senior Member of IEICE, Japan; a Volunteer of the IEEE Bangladesh Section; and a Life Member of the Bangladesh Electronic Society and the Bangladesh Physical Society. He is also the Founding Chapter Chair of the IEEE Bangladesh Section Computer Society Chapter.

MOHAMMAD SHAHIDUL ISLAM received the B.Tech. degree in computer science and technology from the Indian Institute of Technology Roorkee (IIT Roorkee), India, in 2002, the M.Sc. degree in mobile computing and communication from the University of Greenwich, London, U.K., in 2008, and the Ph.D. degree in computer science and information systems from the National Institute of Development Administration (NIDA), Bangkok, Thailand. He is currently an Associate Professor at the Institute of Technology (IIT), Jahangirnagar University, Savar, Bangladesh. His research interests include image processing, artificial intelligence, and machine learning.

MEHDI SOOKHAK (Senior Member, IEEE) received the Ph.D. degree in computer science, major in information security, from the University of Malaya (UM), in 2015. From 2012 to 2015, he was a Research Assistant with the Center of Mobile Cloud Computing Research (C4MCCR), UM. From 2016 to 2017, he was a Postdoctoral Fellow with Carleton University, Canada. In 2017, he joined Arizona State University. In 2019, he joined Illinois State University as an Assistant Professor of cybersecurity. He is currently working as an Assistant Professor of computer science at Texas A&M University, Corpus Christi, TX, USA. He has authored more than 50 articles in high-ranking journals and conferences. His research interests include cloud and mobile cloud computing, fog/edge computing, vehicular networks, blockchain, computation outsourcing, machine learning, and AI. He is on the Editorial Board of several ISI journals, including *Vehicular Communications*, *Electronics*, and IEEE Access. He served as the Chair for several conferences, such as IEEE WTS and IEEE ICC.

ALISTAIR BARROS is currently a Professor of information systems and the Head of the services computing program at the School of Information Systems, Queensland University of Technology. He has 32 years ICT experience across industry, industrial research and development, and academic roles, including the Global Research Leader and the Chief Development Architect at SAP AG. His research interests include cloud, enterprise systems and microservices engineering, evolution, and provisioning using model-based techniques.

MD WHAIDUZZAMAN (Senior Member, IEEE) received the bachelor's degree in electronics and computer science and the M.Sc. degree in telecommunication and computer network engineering from the University of London, U.K., and the Ph.D. degree from the University of Malaya, Malaysia. He is currently a Professor with the Institute of Information Technology (IIT), Jahangirnagar University. He is also works in an ARC funded projects at the Queensland University of Technology, Australia. His research interests include mobile cloud computing, vehicular cloud computing, fog computing, and microservices. He received the Best Paper Award in *Journal of Network and Computer Applications* (Elsevier, Paris, France).