Hindawi
Security and Communication Networks
Volume 2022, Article ID 1270180, 14 pages
https://doi.org/10.1155/2022/1270180

Review Article

Software-Defined Networks and Named Data Networks in Vehicular Ad Hoc Network Routing: Comparative Study and Future Directions

Ishtiaq Wahid,[1] Sadaf Tanvir ,[2] Abdul Hameed ,[3] and Masood Ahmad [1]

[1]*Department of Computer Science, Abdul Wali Khan University, Mardan, Pakistan*
[2]*Department of Computing and Technology, Abasyn University, Islamabad, Pakistan*
[3]*Department of Computing and Technology, Iqra University, Islamabad, Pakistan*

Correspondence should be addressed to Abdul Hameed; hameed@iqraisb.edu.pk

Received 28 February 2022; Revised 28 April 2022; Accepted 29 April 2022; Published 18 June 2022

Academic Editor: Habib Ullah Khan

Routing protocols are an essential component of vehicular ad hoc networks. Software-defined networks and name data networks are new aspects of routing that are coming to the fore as Vehicular Ad Hoc Network technology evolves. Data Network-based VANET routing protocols and Software Defined Network-based VANET routing protocols have been developed in recent research. These newly developed protocols must be part of VANET routing protocol surveys. The taxonomy of traditional routing protocols must take these innovations into account. To the best of our knowledge, no such taxonomy exists at the moment. We present a new taxonomy of routing protocols based on the additional routing aspects of Software-Defined Networks and Named Data Networks. All traditional routing protocols are kept in a single category. This research work aims to update the existing taxonomy of routing protocols with the newly adopted aspects of research in routing. Advanced routing schemes are selected for the survey from each category to evaluate new research results in VANET routing. This article also describes future directions for VANET/ITS routing research.

1. Introduction

An ad hoc network of vehicles is an exciting and challenging area where many applications, such as traffic services, alarm and warning messages, audio/video streaming, and general infotainment, can find their place. Although research in this field spans over two decades, large-scale practical implementation will still take some time [1]. Emerging models in the vehicle industry communicate with one another and exchange information online. As an application of vehicle communication, the Vehicular Ad Hhoc Network (VANET) leads to an Intelligent Transport System (ITS) [2, 3]. In Vehicle-to-Everything (V2X), the vehicles are connected and provide warning and alert messages to the driver regarding road conditions and hazards. The car will interact with its drivers and nearby vehicles [4] and be aware of its environment and road conditions. Future driving will avoid heavy traffic jams and road accidents and ensure road safety.

Each vehicle node in Vehicle to Vehicle (V2V) is a part of a mesh network that transmits, accepts, and retransmits messages when required [5]. The three standards, namely, IEEE 1609, SAE J2735/SAE J2945, and IEEE 802.11p, are used in this network that defines network architecture, message packet information, and physical standard for Dedicated Short Range Communications (DSRC) [6, 7]. DSRC is a short-to medium-range communication service designed to enable communication between vehicles, roadside units, and vehicles (V2V) [6, 7]. Car sensors provide the network's location, speed, braking, and direction [8].

Components from the environment, such as traffic lights and other sensors (placed on the roadside to support the V2X), act as network nodes in this network. Vehicle to

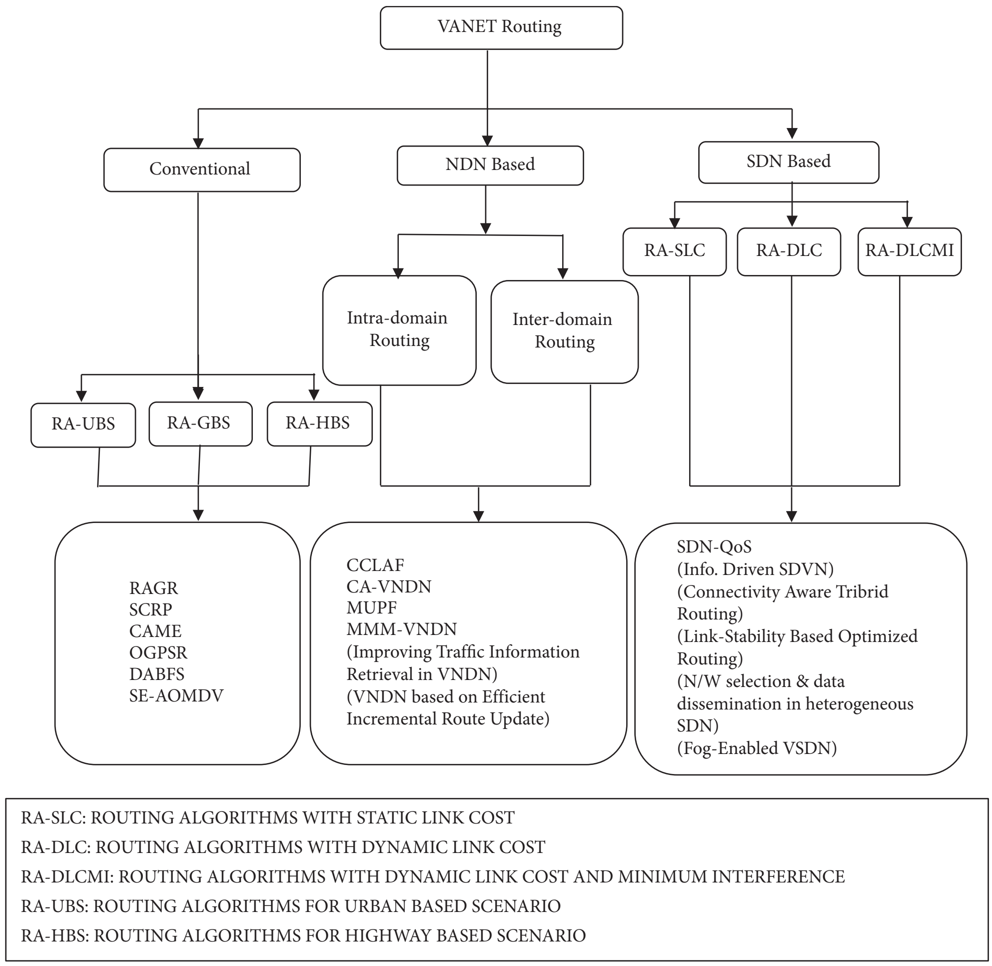

Figure 1: Taxonomy of VANET's routing protocols.

Infrastructure (V2I) allows the nodes to help the network inform the vehicle driver about traffic light timings, roadside signs, and hazards [9]. Figure 1 shows that V2X is a vehicle-to-everything technology. The V2I issues warnings alerts related to traffic signals timing and priority. Vehicle to Network (V2N) informs about real-time traffic, routing, and cloud services. V2V supports collision avoidance safety systems, and Vehicular to Pedestrian (V2P) provides safety alerts to pedestrians and bicyclists [10, 11].

Ongoing research is evolving to improve routing by considering several aspects and stimulating features of VANETs. Besides routing in VANET, the use of Software Defined Networks (SDN) and Named Data Networks (NDN) can enhance the quality of service (QoS). The SDN and NDN can improve the routing in VANET directly by enhancing QoS.

The following section presents these considerations on the design of routing protocols based on the approach proposed in each algorithm (i.e., conventional routing, SDN, and NDN) and their limitations. This survey selects several recent studies for VANET from traditional, SDN, and NDN. These protocols are chosen and clustered based on their outstanding features. The literature has several comprehensive surveys, but the biases for these surveys are on components of conventional routing schemes. It is tough to identify the recent development in QoS optimization through routing protocols in VANETs as parallel research work is in progress in each category of the conventional routing and other newly introduced advanced techniques.

This classification objective is to converge the research studies on the recently emerged popular schemes and prevent efforts on saturated and outdated routing schemes. The benefit is to help young researchers analyze current and state-of-the-art proposed algorithms on the conventional side along with newly emerged strategies in the routing of VANETs. The current state of the art work from five to seven years is selected to extract their working procedure, the pros and cons of the research work, and the distinguished feathers of each proposed scheme. The tables in each subsection show the comparison of simulation, routing, and performance metrics used in the approach of the routing schemes considered.

2. Routing Protocols in VANETs

Routing protocols in VANETs are generally classified based on VANET architecture into V2I and V2V. V2V is categorized further based on transmission strategies and routing information. These are broadcast, multicast, unicast, and position or topology-based [12, 13]. The routing algorithms are also categorized as reactive, proactive, and hybrid, as mentioned in Ref. [14]. Another taxonomy is predictive mobility-based algorithms and power-aware routing schemes. The protocols intend to ensure service quality and efficient usage of limited resources. Cluster-based routing protocol's design purpose is to reduce the topology maintenance overhead. To maintain a congestion-free network with low latency, positioned or topology-based routing schemes are proposed. The current research in VANETs routing considers all these aspects, but the biases for their designed consideration are the approaches adopted for the routing issue resolutions. This article categorized the protocols based on the policies/technologies adopted in resolving VANETs routing issues. It will help the researchers study protocols designed based on their desired used technology. Figure 1 shows the taxonomy of the studied protocols based on the technologies used in the design.

A routing protocol that copes with the topology changes in high-speed VANETs must be designed for two reasons. Firstly, in ad hoc networks, routing is liable for finding and maintaining routes to the destination with features of mobility provision, bandwidth restrictions, and limited power [15, 16]. Secondly, these protocols are proposed for specific scenarios, whereas the topology dynamics in VANET are very high.

2.1. A Conventional VANET Routing. Conventional VANET routing consists of all categories described in previous surveys and studies [17–20]: position-based, topology-based, reactive, proactive, hybrid, DTN, non-DTN, unicast, and broadcast and multicast, etc. We discuss some of the latest protocols from these conventional routing proposals for analysis and the SDN and NDN routing proposals to develop future research directions in VANET routing. The selection criteria for routing protocols for the survey are recent publications in indexed journals, and they are within the conventional, SDN- and NDN-based approach.

2.1.1. Secure and Efficient Ad Hoc On-Demand Multipath Distance Vector (SE-AOMDV). To guarantee safety for vehicle applications, the US Department of Transportation's NHTSA (National Highway Traffic Safety Administration) supports introducing practices to improve vehicle safety in the USA. The NHTSA is developing safety solutions to tackle safety challenges and reduce the consequences of attacks [17]. It is essential to ensure that increasing network security does not affect the QoS delivered. Multiple approaches, architectures, and strategies exist to protect vehicle applications [17].

Before the applications are secured, routing protocols determine the route taken between a destination and a source, using the VANET architecture consisting of a set of Roadside Units (RSUs) that communicate with the On-Board Units (OBU) of the vehicle. RSUs and OBUs connect, called V2I communication, and OBU to OBU communication is called V2V communication.

The improvements to the routing protocols include proposals that aim to find multiple routes from source to destination. The design of VANETs has various multipath routing algorithms. The routing protocol Ad hoc On-demand Multipath Distance Vector (AOMDV) routing protocol [18] is based on the Ad hoc On-demand Multipath Distance Vector (AODV) protocol and can handle network mobility. It is the preferred protocol due to its capability to work in vehicle environments [19]. Due to the ad hoc and distributive capabilities of the VANET framework, routing protocols such as AOMDV are more appealing to offenders who can penetrate the network. There are a bunch of threat scenarios like Selfish driver (redirects the traffic), Prankster (for fun does the DoS or message suppression), and greedy drivers (gets own benefits), etc., in which only those attacks that target the routing protocols [20] are distinguished. A malicious node can exploit the network layer loopholes by distributing packets or disrupting the network routing process. Vehicle authentication, vehicle data protection, unity, integrity, nondenial of the message, confidentiality, and service availability are required to prevent attacks and protect the network [20]. In this paper, the authors enhance the AOMDV routing protocol's security by addressing the security issues without compromising the network's QoS requirements. The proposed algorithm [21], called Secure and efficient AOMDV (SE-AOMDV), can discard fake nodes via the authentication procedure, enhance node disjunction, ensure the integrity of packets delivered, and analyze network behavior to identify routing attacks.

2.1.2. Direction Aware Best Forwarder Selection (DABFS). The nodes often enter and leave communication areas, resulting in continuous topological changes. A route chosen at a given time is not always fixed; instead, it can change later for even a single message to be transmitted. This change can take the form of an increasing or decreasing number of hops, which influences the latency time. Moreover, routes are interrupted at regular intervals, and new routes are defined, leading to network partitions [22]. The network partition leads to the deletion of all messages forwarded on the interrupted routes. These factors result in increased packet loss and latency in the transmission of alerts with lower network throughput. Considering all the issues mentioned above, the authors in Ref. [23] propose a new protocol, Direction Aware Best Forwarder Selection (DABFS). It uses a novel directional Greedy approach to find the best way to distribute alerts in a bi-directional V2V highway scenario. The direction is a significant factor for all topological changes and connection breaks on the routes. DABFS considers the direction of movement of the nodes in addition to the distance parameter to guarantee a reliable and speedy alert delivery. For this purpose, it introduces a Hamming distance function. DABFS suggested using the relative positions as additional parameters to find the most suitable route among the available routes. The relative positions of the source and destination nodes remain essential even during the routing process.

Two significant findings have emerged from this study. The use of directional components and the relative positions of the source and destination nodes improve network throughput and decreases packet loss ratio and network latency; secondly, it allows a VANET routing protocol to take topological changes into account during alert transmission. The results show a significant reduction in latency times for the dissemination of alerts when compared with the existing routing schemes.

2.1.3. Road Aware Routing Protocol (RAGR). The geographical routing protocols have many advantages over topology-based routing. However, geographical routing protocols face difficulty finding the optimal path and selecting the next best hop due to volatile links, link breakage, and signal attenuation in urban scenarios [24]. A routing protocol design is needed to overcome these issues that consider the suitable and appropriate metrics such as direction, distance, and traffic density for data forwarding in multi-hop urban scenarios and high mobility in VANET.

Qureshi et al. in Ref. [24] propose a Road Aware Routing Protocol (RAGR) to relay packets of data in city areas. The biases of the proposed protocol are direction, distance, and traffic congestion routing metrics to solve the delay and packet loss issues in city VANETs. RAGR selects the best node for data forwarding in the network using distance and direction information. The following route at intersections is selected using link quality, distance to destination, and traffic density analysis. The proposed protocol is validated for performance against CGMR, SDR, and GyTAR using the NS-2 simulator.

There are two kinds of operations in the RAGR protocol: selecting the next forwarding node and selecting the following route at the intersection. Both processes need computations and maintained sets of information, increasing routing overhead. Additional communication is necessary for the supported set of data.

2.1.4. Stable Connected Dominating Set-Based Routing Protocol (SCRP). The grid environment is required for infotainment applications to avoid delivery delay and achieve high throughput in vehicular ad hoc networks. It is not simple to be completed in urban scenarios where the vehicle density estimation in a region is difficult due to fluctuation in traffic flow from day to night and downtown to suburbs. The vehicles distribution over different areas is uneven since the vehicle density converges at intersections. In addition to obstacles in urban scenarios, these challenges make intersections ideal for routing decisions. A series of routing protocols are proposed to consider these observations as greedy approaches. Routing decisions in GPSR, GSR, and GPCR are based on the shortest path between the source and the destination. The GyTAR, A-STAR, RBVT [25], and IGRP [26] select well-connected road segments to forward packets toward the destination. Due to greedy approaches, these protocols suffer from congestion and maximum local problems.

The stable CDS-Based Routing Protocol (SCRP) proposed in Ref. [27] is a distributed geographic routing scheme. SCRP is based on a global network topology that selects the routing paths with minimum end-to-end delay. It calculates end-to-end delay for a routing path before data transmission. SCRP considers spatial distribution and vehicle speed to build backbones on the road segments using the Connected Dominating Set (CDS). With updated network topology, the bridge node connects these backbones at intersections and monitors delay. SCRP uses this information, labels every road segment with weight, and establishes a routing path using low-weighted road segments.

There is no defined mechanism in SCRP for the maintenance of backbones. Scalability issues may arise in a flat network as VANETs do not have routers and many mobile vehicles. The local maximum problem of greedy schemes is removed at the cost of computational overhead and routing overhead.

2.1.5. Optimized Geographic Perimeter Stateless Routing (OGPSR). Many position-based routing schemes have been proposed for VANET. GSR is designed for city scenarios but does not consider the junction. GPCR is a greedy-based routing that forwards the packet to a junction rather than passing it across the intersection. GPSR is another position-based routing that locates the nodes using GPS and is most suitable for VANETs. Therefore, several improvements to this strategy, such as Greedy Perimeter Stateless Routing with Movement Awareness GPSR-MA [28] and The Moving Directional Based Greedy MDBG) [29]are proposed. GPSR-MA considers distance, movement of nodes, and speed while making route decisions. Another up-gradation to GPSR is presented in Ref. [30], which uses a formula based on the distance and triangular area of the relay that determines the forwarding node. The MDBG routing solves the directional issue in greedy schemes. It determines the direction of nodes by hello messages, destination requests, and destination replies. The technique proposed in Ref. [31] selects an efficient route using the Hello Packet. It solves the local maxima problem in GPSR, but it does not consider the delay here.

The proposed Optimized GPSR [32] solves the issue in greedy schemes to ensure the proper selection and right direction. The greedy criterion in GPSR is to find the forwarding node based on distance toward the destination. Therefore, there is a chance of wrong selection and wrong direction. Another direction parameter is added to the selection criteria to avoid this issue. OGPSR uses the arc tangent rule to select the forwarding node in the right direction. Each tangent arc improves the greedy forwarding mechanism assuming the horizontal and vertical reads with two lanes.

In the related work, the author discusses GPSR-MA, MDBG, and other improvements to GPSR. The proposed scheme checks for performance against the improved approaches as well. The parameters do not show the transmission range of the nodes, which makes it challenging to analyze the results for specific parameters. The performance improvement in urban scenarios is not satisfactory.

2.1.6. Connectionless Approach for Vehicular Ad Hoc Networks in Metropolitan Environment (CAME). Most of the proposed geographical routing schemes in VANETs need to establish a route from source to destination. These connection-oriented protocols have only one path for data transmission. Due to low vehicle density, the single established route may suffer disconnection. The protocol needs to send more control messages that may cause end-to-end delays to recover the static route. The solution to the issues is proposed in Refs. [33, 34] as multipath routing protocols. The control packets' messaging is an issue. Therefore, connectionless routing protocols are proposed [35, 36] that do not need to establish a route for data transmission. The relay nodes are selected according to topological change and vehicle mobility, but routing schemes need improvement to address the average end-to-end delay.

The authors of Ref. [37] propose a connectionless approach for VANETs in urban environments named CAME. The proposed scheme uses different delivery strategies for packet delivery following changes in topology and does not establish a route in advance. It has different routing strategies for straight roads and intersections. It develops a reference line to assist the relay node selection procedure and the next relay to the destination node. In this way, the source node communicates with the destination. It also considers the data flow and avoids congestions and disconnection to ensure packet delivery to the destination node. The proposed scheme minimizes end-to-end delay and increases the packet delivery ratio with minimum control overhead.

The proposed scheme has an additional computational overhead for mode selection and location discovery. It is a repeated process for every following relay selection, which may cause end-to-end delay. The average number of hops used in data delivery is an essential factor to be checked. Tables 1–3 summarize the routing parameters, simulation parameters, and performance metrics, respectively.

2.2. Named Data Networking (NDN). NDN names the data content instead of the end-to-end devices. In NDN, the interest packets are sent by the consumer. Upon receiving the interest packets, the content provider forwards the content data on the interest packets' path. In VANET, this can support several applications based on consumer interest.

Figure 2(a) shows the VANET architecture with conventional IP-Based networking, and Figure 2(b) shows the VANET architecture with NDN networks.

2.2.1. Content Connectivity and Location-Aware Forwarding (CCLAF). Routing protocols and techniques used in VANETS are physical structure-based; these schemes have high costs due to the movements of vehicles resulting in continuous updates of the forwarding tables. Geographic information systems can use a popular approach like forwarding packet techniques to produce data. However, such schemes can broadcast location information to restore the data. NDN is a network architecture used in Internet architecture closely related to the Data-Centric communication model. It can send the data of interest to retrieve the required data. Communication networks can use the data-centric approach, but this approach is inefficient for tracking and producing data in vehicular networking.

By evaluating the problem of data tracking and producing in VANETs, this paper [40]evaluates a novel forwarding technique for NDNVANETs called Content Connectivity and Location-Aware Forwarding (CCLAF). This technique can determine data location information and vehicle content connectivity. Every vehicle must receive interest and should set a waiting timer that forwards the interest when the timer expires or discards it when it hears another node delivering the interest. CCLAF technique does not depend on the location information, which is very strong compared to other VANET forwarding strategies as vehicle location changes rapidly due to node mobility. This scheme can tackle the flooding problem.

2.2.2. Context-Aware Data Dissemination for ICN-Based Vehicular Ad Hoc Networks (CA-VNDN). Through interfacing with different vehicles, individual gadgets, and the encompassing environment, a vehicle can spread and accumulate traffic and ecologically related information and give corresponding chances to sanction new portable and social applications to travelers. Therefore, VANETs have been a hotly debated issue for years. As of late, with regards to data provisioning, VANETs have been viewed as an approach to build income for specialist co-ops and vehicle makers. The exceptionally unique, versatile, and remote transmission condition has brought about numerous issues that have reduced information transmission productivity and have affected information conveyance in VANETs.

This paper [41] proposes a context-aware packet-forwarding working together for ICN-based VANETs. The proposed scheme considers the distribution and density of vehicles while broadcasting the data to reduce the broadcast storm of interest packets. Limiting the nodes around the intermediate forwarding nodes minimizes the number of forwarded interest packets, resulting in an increased data delivery ratio.

2.2.3. Multi-Hop, Multipath, and Multichannel NDN for VANETs (MMM-VNDN). Vehicular Ad Hoc Network has many applications like safety, video streaming, location tracking, broadcasting, weather applications, and road accident warnings [42]. In VANETS, end-to-end delay is not scalable; these applications need stable end-to-end connectivity with a server with some information. When vehicles make their movements at a very high speed, they change their location unpredictably. Varying wireless connectivity problems lead to poor QoS and QoE.

A new version of the routing technique is proposed to address the above issues, like Multi-hop, Multipath, and Multichannel NDN for VANETs (MMM-VNDN) [43]. This

Table 1: Routing parameters of conventional VANETs routing protocols.

Ref.	Name of the proposed protocol	Routing parameters/Features					
		MAC protocol	Transmission range	Operational scenarios	Speed	No. of nodes	Topology size
[23]	DABFS	NA	150 m	Bi-directional highway	0–42 m/s	0–500	5000 m^2
[21]	SE-AOMDV	802.11	NA	NA	18–108 km/h	NA	1500 m^2
[24]	RAGR	IEEE 802.11 b DCF	300 m	Urban scenario	25–50 km/h	100–350	3968 m^* 1251 m
[27]	SCRP	NA	250 m	Urban scenario	30–80 km/h	150–600	7500 m^2
[32]	OGPSR	IEEE 802.11	NA	Urban map scenario	10–20 m/s	50–125	500 m^2
[37]	CAME)	IEEE 802.11p	300 m	Metropolitan environment	0–20 m/s	5–25 per 100 m	1000 m^2

Table 2: Simulation parameters of conventional VANETs routing protocols.

Ref.	Simulation features							
	Simulation tool	Compared to	Packet size bytes)	Data rate kb/s)	Traffic type	Channel capacity	Simulation time	Mobility models
[23]	Matlab R2018a	CADD, GPSR, PA-GPSR, and ID- LAR	NA	NA	Bi-directional highway	NA	NA	Highway
[21]	NS-2.35	AOMDV	512	11.4 mb/s	CBR	NA	1000 sec	Random waypoint
[24]	NS-2.34, MOVE, and SUMO	CGMR, SDR, and GyTAR	512	3 mb/s	NA	NA	500 sec	Urban scenario
[27]	NS-2, MOVE and SUMO	iCAR, GyTAR and GPSR	512	NA	NA	NA	NA	Urban scenario
[32]	NS-2	GPSR	512	NA	NA	NA	100 sec	Urban map scenario
[37]	NS-2, MOVE	WPB, CLA-S	512	NA	NA	NA	100 sec	Metropolitan environments

Table 3: Performance metrics of conventional VANETS routing protocols.

Ref.	Performance metrics					
	Packet delivery ratio	End to end/ average delay	Throughput	Packet loss	Routing/message/ communication overhead	Other metrics
[23]	No	Yes	No	Yes	No	NA
[21]	Yes	Yes	Yes	Yes	Yes	Normalized routing overhead
[24]	Yes	Yes	No	No	No	NA
[27]	Yes	Yes	No	No	No	Control overhead, control packets
[32]	No	Yes	Yes	No	Yes	NA
[37]	Yes	Yes	No	Yes	No	Control overhead, control packets

strategy exploits several paths to achieve more efficient content retrieval. New enhanced protocol, improved MMM-VNDN (iMMM-VNDN), makes paths between a requester workstation and a provider by broadcasting Interest messages. A provider workstation responds with a data message to a posted Interest message, which creates unicast routes between nodes by using the MAC address(es) as every workstation's specific address(es). IMMM-VNDN extracts and thus creates routes based on the MAC addresses from the NDN messages. Results show that our routing strategy performs better than other state-of-the-art strategies in terms of Interest Satisfaction Rate while keeping the latency and jitter of messages low.

2.2.4. Improving Traffic Information Retrieval in VANET with NDN. NDN refers to an information-oriented network architectural proposal. NDN concentrates on retrieving named data rather than delivering point-to-point packets. The network directly identifies the named and immutable data, and the data are "pulled" by explicitly requesting data (interest) instead of being "pushed out" and shared between endpoints of communication as in TCP/IP. The ICN for VANET is friendlier because NDN is not connection-based; in comparison to IP-based approaches, NDN-based approaches do not need to change the underlying network layer principles.

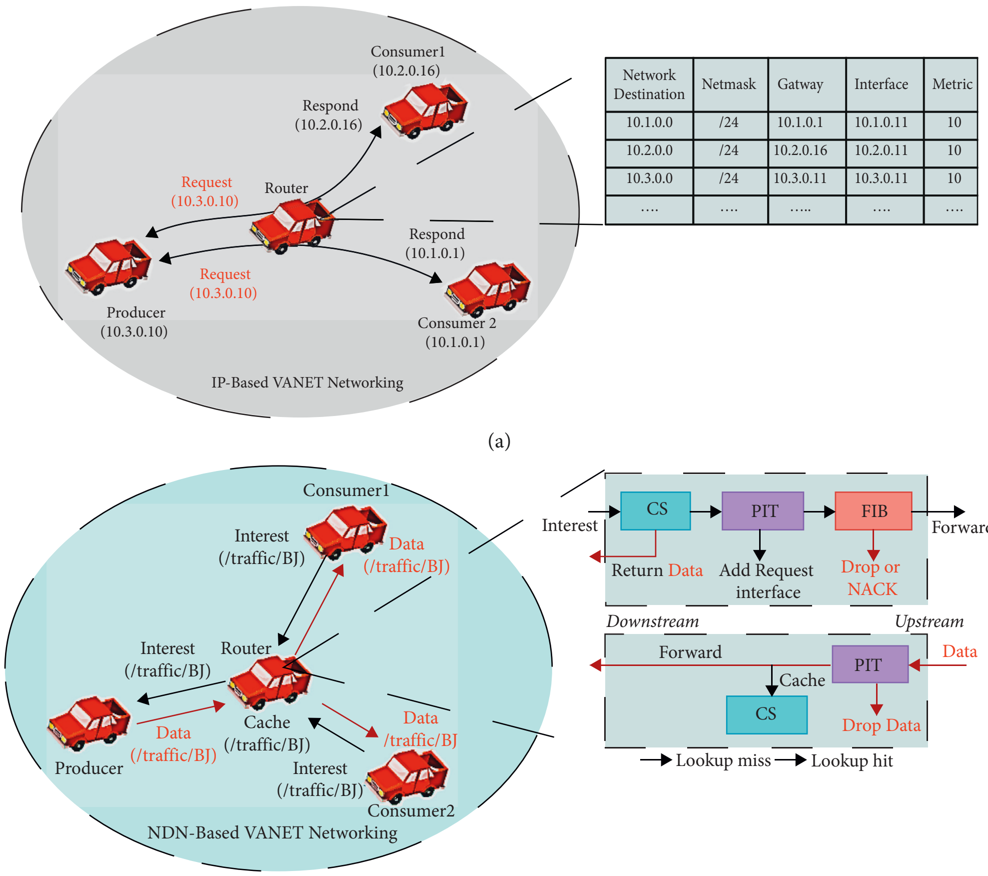

Figure 2: (a) VANET architecture with IP-based networks [39]. (b) VANET architecture with NDN networks [39].

This paper [44]proposes a provisional concept for the retrieval of traffic data in VANET with NDN to provide support at the network layer for decentralized Traffic Information System (TIS). The design aims to use the data-centric communication model to redefine forwarding in VANET. A significant problem for VANET in the context of TCP/IP is the forwarding of packets to a highly dynamic specific endpoint. NDNs' data-centric communication model frees itself from explicit locators such as IP addresses and transforms the routing problem into the routing of interest to potential data sources, i.e., routing of interest to places where data can be found.

The authors transform the issue of forwarding interest of a vehicle at a specific moment in time into the series of management of interests by activating active caching of vehicle data into an area where the probability of achieving the desired data is maximized. Three actions are taken to accomplish this objective. First, by designing the application namespace, Geo-localization is integrated into the data names so that the name marks the location of the traffic information included in the data. Secondly, the updated data are made available in the region near the source of traffic information. The said information is possible through the dissemination and caching algorithm that drive a vehicle as an effective data carrier based on updated adjacent traffic information. Thirdly, a name-based collision avoidance policy is used to serialize the transmission of data, i.e., randomly distributed with timers, and through suppression of needless communications. The number of messages is reduced, each based on the name of the packets received. The proposed design is implemented/evaluated with ndnSIM [45].

2.2.5. *Multiple Unicast Path Forwarding in Content-Centric VANETs (MUPF).*

TCP/IP architecture for VANETs is not appropriate, and some researchers are considering the ICN architecture for VANETs. In VANETs, two main problems in the routing process have been discovered. First, most strategies broadcast the packets (interest and data), taking full advantage of the wireless channel, but it must only go to the following content node for the interest. Much of the packets that create flooding are not needed, and if these packets spread across the network, this can lead to collisions, and the surplus traffic causes a significant reduction in network performance. Conversely, VANET's network environment is dynamic, nodes topology often changes with the movement of vehicle nodes, and connections between dynamic nodes are susceptible to being interrupted by leaving the nodes, interrupting the delivery of packets, and even triggering a series of repetitions.

Therefore, this paper suggested a scheme for building multiple unicast forwarding paths called MUFP. This scheme is designed to create several stable unicast forwarding paths in VANETs that are content centered, and its basic concept can be described as follows:

A content discovery process in MUPF [46] is designed to find the relevant content nodes of interest quickly. So once MUPF knows where the content nodes are, it can build the direct routing paths instead of an undirected transmission. Secondly, it can improve routing path reliability, implement motion parameters, and link quality metrics to the MUPF route building process. In selecting the next hop, both clustered and flat strategies consider the specific parameters of the nodes, fetch the next hops having a longer link time and a more vital link state with the local node, and enhance the tolerance in the time of the routing paths.

The benefits of the proposed scheme is that it prevents the use of broadcast in packet forwarding. According to each request of interest, MUPF will create several stable unicast paths and return the data packets to opposite directions, efficiently reducing the surplus of useless network traffic. Secondly, MUPF introduces the parameters of motion of routing nodes and link quality metrics (Link lifetime, link available probability) to handle frequent changes in network topology causing a connection termination and to enable the selection of stable and reliable next hops. In addition, computational findings indicate that MUPF efficiently cuts transmission delay and response time and improves cache hit rates.

2.2.6. Vehicular Named Data Networking Based on Efficient Incremental Route Update. VANET's high vehicle mobility and the vulnerability of wireless communication complicate the maintenance of stable network topology. Implementing reliable and efficient data routing in networks with high dynamic characteristics is not easy. NDN technology is a promising ICN approach replacing the IP address of a host with a naming and routing scheme based on information to separate the identifier from the address. A consumer node in NDN submits a package of requests for data and a data provider responds to the request by supplying the data packet. The data packet is requested and forwarded by the data's content (or ID) and not by the node's address. Such a scheme is suitable for VANETs where routing to IP addresses is impossible.

This article [47] focuses on the vehicle-intensive scenario of infotainment distribution via V2V communication. Infotainment data can be images, video files, or other files. The primary objective is to lower the routing table cost in the established VNDN. Typically, as a vehicle moves into a new road section, the maintained routing table is deleted and rebuilt, which is expensive. Instead, an incremental mechanism is developed to update the route. When a vehicle enters a new road segment, the current routing tables can be corrected by adding and deleting table sets automatically and interactively instead of rebuilding the entire table.

2.2.7. Merits and Demerits of NDN in VANET. NDN in VANET is still an active research topic, and the process of improvement for specific applications of VANET is evident with current research in this domain. The future Internet architectures and V2X communication can use the NDN concept for efficient and fast communication. However, in the VANET environment, the NDN may face several challenges due to its high mobility and frequently changing topology. Secondly, the nonuniform distribution of vehicles, data flooding, and broadcast storming is challenging and needs to be addressed efficiently.

Tables 4 and 5 show the simulation specifications, application type, communication model, evaluation parameters, naming scheme, caching scheme, and forwarding strategies used in the proposed NDN scheme.

2.3. Software-Defined Networking. Software-Defined Networking (SDN) divides the communication protocols functionalities into two modules, i.e., routing decisions or communication policies and data forwarding. The procedures in SDNs are in centralized control, and the policies are usually implemented on fixed infrastructure/roadside units (RSU) rather than mobile devices. The mobile devices are used to forward the data according to the policies defined centrally. The well-known protocol used for centralized control is OpenFlow. SDN-based VANET architecture is shown in Figure 2.

2.3.1. SDN-Based Mobility Management and QoS Support for Vehicular Ad-Hoc Networks. Due to their unique characteristics, VANETs are divided into self-contained and distributed networks. The SDN paradigm is based on the central control principle. The consideration of SDN for VANETs is a difficult job. However, few aspects of vehicle networks can be used in conjunction with SDN principles. For instance, with a GPS service for road maps, vehicles follow a predictable topology, enabling the optimization of traffic with a global network view.

There are additional challenges in considering SDN for VANETs. In case of the constant fluctuations in link/channel conditions and the calculation of the centralized route with significant computation, the SDN principles cannot simply be extended to vehicle networks. The smooth transfer of vehicles between multiple domains is a difficult task. Computing intensive management of mobility can choke the control level of global controllers. Further regulations are required to cope with the sparseness or density of ever-changing topologies. The inconsistent network traffic of multiple coexisting radio access technologies leads to additional complexities.

In Ref. [38], the authors proposed an SDN-based hierarchical architecture to solve the problems by integrating multi-tier design and leveraging the power of cloud computing. The proposed model has global controls and onboard units (OBUs). The global centralized controller is placed in the cloud, and the local controllers are deployed in OBUs. The cloud has a single global controller, and every vehicle has an OBU, which makes this physically distributed control and logically centralized. Global Control includes the core modules that form the building blocks of control

Table 4: Specifications of simulation parameters and application type of NDN schemes proposed for VANETs.

Ref.	Application type	Comm. Model	Simulation tools	Parameter evaluation
[44]	Traffic information retrieval	V2V	ndnSIM	No. of transmitted packets, pushing range
[47]	Information dissemination	V2V	Sumo, ndnSIM	Hit rate, avg. Delay, avg. fwd time
[46]	ITS data forwarding	V2V	ndnSIM2, VanetMobiSim	Hit ratio, avg. Response time, TCP
[48]	Robust forwarding, reduce interest flooding	V2V	No simulation	Message overhead, fetching rate
[43]	QoS routing	V2V	ndnSIM, SUMO	Avg. Latency, avg. hit rate, avg jitter
[41]	Data dissemination	Not mentioned	ndnSIM, SUMO	Data delivery ratio, pkt. loss rate, b/w usage, data response time, and traversed hops

Table 5: Forwarding, caching, and naming schemes used in NDN schemes.

Ref.	Forwarding scheme	Caching scheme	Naming scheme	Simulation
[44]	Geo-location and name- based	Unsolicited data caching	GPS-based naming	YES
[47]	Geo-based forwarding	No caching	Common naming	YES
[46]	Multiple unicast path forwarding	Nearest content caching	GPS-based naming	YES
[48]	Content connectivity and location-aware forwarding	Not mentioned	Not mentioned	NO
[43]	iMMM-VNDN	Not mentioned	Not mentioned	YES
[41]	Context-aware packet forwarding	In-network caching	Hierarchical naming	YES

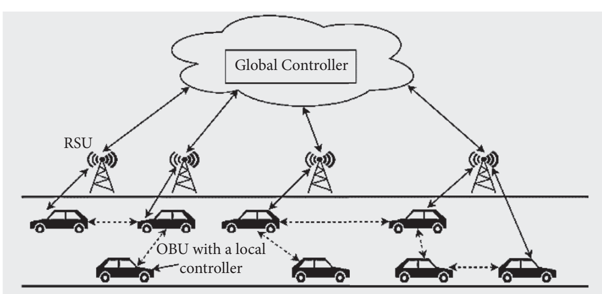

Figure 3: SDN-based VANET architecture [38].

capability and serve as the platform for implementing and deploying different applications at the control level.

Moreover, the global controller has a repository of centralized databases for a coherent view of topology and other network-wide activities used by the planner to deploy QoS-based queues and enforce the specific policies. In the V2I model, vehicles communicate with global control through roadside units (RSUs). RSUs use the global controller's services following the nodes' requirements in their service areas.

2.3.2. Information-Driven Software-Defined Vehicular Networks. Multiple features of VANETs and applications complicate content delivery more than traditionally done via the Internet [49]. Firstly, several applications are to be devised or proposed, and the content delivery systems need to be robust for the deployment of new applications. The applications are called push-based for some of their objectives, meaning content should be delivered to clients without a request. Moreover, in VANETs, intermittent contacts increase end-to-end connection establishment and maintenance costs. In addition, VANETs are expected to address and route geo-based and information-centric rather than host-based as on the Internet. Furthermore, the mobility of vehicles results in constant changes in topology, which leads to scenarios with high dynamics. After all, in many applications, content is time and location dependent, i.e., it is valid if it is within a certain period within a region of interest (RoI).

The authors in this article [50] propose an information-driven, software-defined vehicle network architecture providing vehicle applications with content delivery services. The architecture integrates the communication scheme for information-centric networks (ICN) with the paradigm for SDN and extends and adapts the concepts to the characteristics of VANETs. Therefore, content delivery in the proposed architecture is information-driven, and the SDN components can adjust the rules governing the process according to the latest status of networks. The result shows that VANETs can benefit from this integration.

2.3.3. Connectivity Aware Tribrid Routing Framework for a Generalized Software Defined Vehicular Network. Under lack of network coverage, the SDN control level may not always receive updated network information and may not be capable of reaching the required paths [51]. Even rapidly changing network areas, such as highways and cities, quickly make obsolete the current network information. The abovementioned cases can create black trails (areas with outdated or no network information) in the topology. The improvement in the use of the routing protocol is discussed, and some of the distributed routing techniques like Broadcasting and Store, Carry and Forward (SCF) are integrated with a unicast protocol.

One of the goals is to make the routing protocol independent of the network constraints. In contrast to other networks, vehicle networks may be dense or sparse, dependent on time, location, etc. The same area may be congested at peak hours and sparse at night. Current VANET routing protocols usually target a particular network condition. This paper gives an articulation of jmüñü, the generality in VANET, and suggests an improved scheme to find optimal SCF routes with minimum storage time for sparse environments.

The authors proposed a tribrid routing protocol consisting of broadcast, SCF, and unicast techniques for a broad vehicle network [52]. The emphasis is on maximizing the packet delivery rate in line with the existing latency-based QoS. An incremental algorithm is used in the routing model to assess the feasibility of successive shortest paths in terms of latency and stability based on QoS. The occurring disruptions are treated on a case-to-case basis with broadcast and SCF routing algorithms.

2.3.4. Link Stability–Based Optimized Routing Framework for Software Defined Vehicular Networks. Studies have shown that with VANET, the life of the route decreases significantly if a path is made up of three to four hops and resulting in a route error. The distributed VANET routing protocols have difficulty solving this dilemma as it is difficult to accurately estimate the route's validity because of a lack of global network information. As a result, the routes estimated may not be stable until the packets pass, which is likely to drop the packet. This issue becomes serious when a significant amount of time is required to transmit the packets, resulting from a series of packets being sent and/or selecting a long route; the loopholes in both cases increase. Due to a route break, likely, the packets will not reach the destination at the end of the sequence, resulting in lower packet delivery ratios (PDR). Therefore, the system is often forced to new routes, leading to higher latencies.

The global network information is provided by the recent deployment of the SDN in the vehicle domain [51]. Thus, the resulting software Defined Vehicular Network (SDVN) offers an aerial image of the network to check the connection's stability better. Even though there are new ways to explore different routing attributes like stability, the focus is on the shortest path finding [53].

Contrary to the existing studies, the authors proposed in Ref. [54] an optimized new packet routing protocol for SDVN, which considers several aspects of stability and distance. The objective is to choose a set of (on-demand) shortest paths that are collectively stable enough to deliver a given number of packets. The entire issue is modeled after a cost-optimized flow issue and then linearized to an Integer Linear Programming (ILP) issue. An incremental packet assignment scheme is adopted as a computational optimization technique using bidirectional and K shortest path algorithms.

2.3.5. Network Selection and Data Dissemination in Heterogeneous Software-Defined Vehicular Network. Existing vehicle communication research is based on the IEEE 802.11p standard only; mobile networks use data offloading via two network interfacing and consider heterogeneous networks [55]. Vehicle communication based on the IEEE 802.11p standard leads to problems with interrupted network and broadcast storms at low and high vehicle densities, worsening the packet delivery rate and resulting in data dissemination delays. The mobile network increases communication costs with more handovers in BS [56]. Applications in today's vehicle network have different requirements. Therefore, existing communication systems with homogeneous technology, data offloading, and vertical handoff may not be capable of meeting the very other needs of new applications. Moreover, existing methods did not fully utilize the network resources available due to the network's inflexibility. The authors apply the SDN paradigm to vehicle communication in heterogeneous network environments and different applications of VANETs.

The fifth-generation mobile network (5G) has the potential to improve the performance of vehicle communications with enhanced connectivity and the lowest latency [57]. In developing VANETs with 5G networks, SDN enables the use of network resources efficiently by breaking the link between data transfer and network management [58]. Moreover, SDN enables seamless handover, bandwidth utilization, load balancing, and interoperability across heterogeneous networks using wireless network management. Therefore, SDVN with 5G technology is a possible network architecture to fulfill the diverse needs of VANET applications.

The authors in Ref. [59] proposed a new approach based on the architecture of SDN for network selection. This approach involves a centralized network selection at the SDVN control layer. The controller can select the optimal network interface adaptively from the available networks when an application needs to transmit data. This mechanism allows the controller to assign the network according to the requirements of an application. Assuming an application that requires more bandwidth and less latency, the controller sets a mobile network for communication between the controller and the data layer. The application meets the bandwidth requirement and minimizes network management's latency time. 802.11p-based or other low-cost wireless interface is assigned to low-bandwidth applications. The authors have formulated a decision process that includes a network discovery manager, priority manager, network filter, and network selection manager. Network selection is based on Stackelberg's game theory approach [59], which models the interaction between the controller and the networks. The controller selects the network based on the benefit/payoff and uses this network to transmit the data to the vehicle. The data dissemination approach uses the stability of links as a metric for selecting the best route from sender to destination. This mechanism allows the efficient transmission of data for heterogeneous application requirements.

2.3.6. Vehicular Software-Defined Networking and Fog Computing: Integration and Design Principles. Facilitating collaboration between vehicles and infrastructures, Vehicular Networks (VN) provide value-added services ranging from reducing accidents to route recommendations and entertainment. Several research activities have been dedicated to the study of different UN features, such as traffic control, road safety, social patterns, and computational and network requirements [60]. The VNs are on the verge of evolving with new paradigms as vehicles search directly for content irrespective of supplier.

Fog Computing offers cloud systems deployed closer to users to meet processing and delay requirements with minimal help from the Internet Infrastructure [61]. A vehicle supports a fog node to download the global traffic data from the cloud an78 d upload local traffic data via the network infrastructure (V2I and V2V). Fog nodes can be placed at different levels, ranging from the dedicated servers in the wireless or core network to the vehicles. For example, vehicles may generate and utilize a lot of data with the property of local relevance (either timely or spatially). The collaboration between Fog and Cloud Computing must be seamless to create benefits for both users and network/content providers, considering heterogeneous VNs running different access technologies.

The fog cloud integration improves usability without burdening V2V communication [62]. For example, a fog node enables better traffic lighting control to shorten waiting times at intersections and fast accident rescue to improve emergency response. Despite the recently introduced new ways like SDN, which are flexible and efficient to configure and manage the network such SDN [63], the current network infrastructure and the individual management of each wireless network that forms VN still limit the discovery of Fog Infrastructures for scalable VN services.

In this article [64], the authors examine a VN architecture of SDN, known as VSDN. The authors read the SDN architecture design principles based on vehicle fog computing. The cloud orchestrates and controls the fog nodes centrally in the VSDN architecture. Moreover, the design principles for a VSDN architecture should allow content distribution to efficiently provide many vehicle users with all kinds of communication technologies and devices. VSDN's architecture design principles are the main contributions. It focuses on the system's perspectives, networking, and services that SDN will consider to improve the use of fog nodes. This is an application case in which a rapid traffic accident rescue management system of vehicles is put into action using accurate traffic data based on the information related to accidents. The main issue is the analysis of such a scenario where integration of VSDN and fog computing nodes can minimze the arrival time of emergency vehicles at the scene of an accident. It identifies possible challenges and research opportunities for integrating SDN and fog computing in VN environments consisting of heterogeneous wireless technologies.

2.4. Merits and Demerits of SDN in VANET. The SDN simplifies configurations and programming for the changing requirements of the system and future improvements. Secondly, the forwarding policies for different situations or environments in VANET can be designed differently and efficiently. The challenges due to frequent changes in topology are covered up. However, centralized control has its limitations, and SDN centralized control needs infrastructure, whereas in VANET V2V communication, it will be challenging to provide centralized physical control. In logically centralized management, the network needs all-time Internet availability. The VANET is in test implementation with conventional routing protocols, and the hardware vendors have developed hardware to support these protocols. The VANET is expected to be fully implemented by 2024, and the investment made in this regard cannot be discarded easily. Table 6 shows the specifications used in the proposed studied schemes for VSDN. Table 6 is shown below.

2.5. Evaluation and Future Work. The objective of this research work was to provide a comprehensive taxonomy for routing protocol studies that cover all the directions of recent research, from traditional routing to a newly emerged scheme for routing. In this way, the researcher can find studies for an efficient routing protocol in vehicular ad hoc networks that meet the requirement of the modern intelligent transportation system. A brief survey of the state-of-the-art routing protocols in VANETs was conducted to achieve this milestone. We analyzed the pros and cons of each of the protocols and identified the causes of their deficiency. This is summarized in a table showing the considered operational scenario, performance metrics, simulation tool used, no. of nodes, and speed, density, and simulation time of the proposed protocols. It was found that the realistic mobility model and the design of protocols to perform in a specific operational scenario are the main reasons for inconsistency in performance in a dynamic environment of VANETs. Based on these findings and literature study, this study proposed two different protocols that work over realistic mobility models and provide optimal and consistent performance in vehicular ad hoc networks. Firstly, Ref. [65] is our previously proposed supervisory protocol that automatically selects the appropriate routing protocol according to the underlying network environment. This supervision is controlled centrally. We can use the concept of SDN to implement the policies of supervisory protocols centrally. Secondly, Ref. [66] is another scheme for quality-of-service aware cluster-based routing. QoS aware routing distinguishes between delay-tolerant and nondelay tolerant data. It routes the delay-tolerant packet on the cluster-based strategy and nondelay tolerant data on flat routing to utilize the network capability per data requirements. We can use the NDN concepts here to identify the packets for delay sensitivity. However, implementing SDN concepts designed for data-centric networks in VANETs would also be challenging. This shift will require years of research to gain the performance level of conventional VANET routing protocols in terms of stability and reliability. The literature shows that the performance of SDN-based routing is better than traditional routing but for specific services and in certain ideal situations. Therefore, we recommend using the SDN concept with the existing architecture to overcome the current conventional routing

Table 6: Specifications of SDN proposed for VANET.

Ref.	Controller	Architecture	Simulator/southbound API	Applications/use case	QoS Support	Network type
[38]	ONOS	Centralized cloud-based	FlowVisor	SDN-rout, SDN-QoS	YES	Cellular network
[64]	Not mentioned	Centralized	OMNet++, SUMO	Fast traffic accident rescue	No	Cellular network
[50]	Not mentioned	Centralized	OMNet++, SUMO	Efficient content delivery	YES	IEEE 802.11p, 1609
[52]	Not mentioned	Unicast centralized, broadcast distributed	Open-street map, NETEDIT, SUMO	Routing efficiency	YES	DSRC
[54]		Broadcast distributed	NS-3, SUMO	Routing optimization	YES	DSRC
[59]	Openflow	Hierarchical controllers	NS-3.26, SUMO	Network selection and data dissemination	YES	3G, wi-fi, WiMAX, and DSRC

protocols' unaddressed issues or improve the efficiency of existing routing protocols. The SDN and traditional routing hybrid can achieve reliable VANETs routing with efficient performance in future work. Similarly, the NDN concept can distinguish between delay-tolerant and nondelay tolerant data, and the SDN can configure the forwarding policies accordingly. In this way, the future VANETs routing will have the conventional routing supported by SDN and NDN for efficient performance and reliability.

3. Conclusion

The existing conventional VANET routing protocols have reached a level of implementation. Further research in traditional routing is ineffective as the newly adopted routing aspects evolve. For the survey of the routing protocols, the study's dire requirement is to study the recently emerged scheme for routing along with the conventional techniques. This research work provides a novel taxonomy for future research studies in routing and the applicability of the newly emerged techniques in the existing system as future research directions.

Data Availability

The data are available on request. All such requests should be made to the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] S. Boussoufa-Lahlah, F. Semchedine, and L. Bouallouche-Medjkoune, "Geographic routing protocols for Vehicular Ad hoc NETworks (VANETs): a survey," *Vehicular communications*, vol. 11, pp. 20–31, 2018.

[2] M. A. Al-Shareeda, M. Anbar, I. H. Hasbullah, and S. Manickam, "Survey of authentication and privacy schemes in vehicular ad hoc networks," *IEEE Sensors Journal*, vol. 21, no. 2, pp. 2422–2433, 2021.

[3] L. Rivoirard, M. Wahl, and P. Sondhi, "Multipoint Relaying versus Chain-Branch-Leaf Clustering Performance in Optimized Link State Routing-Based Vehicular Ad Hoc Networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 21, 2019.

[4] S. S. S. Kumar, M. J. L. Iqbal, J. S. Sujin, R. Sowmya, and S. D. Kumar, "Recent advancements in automation to enhance vehicle technology for human centred interactions," *Journal of Computational and Theoretical Nanoscience*, vol. 16, no. 2, pp. 550–556, 2019.

[5] C. Rus, R. Marcus, L. Pellegrini, M. Leba, M. Rebrisoreanu, and A. Constandoiu, "Electric cars as environmental monitoring IoT Network," in *Proceedings of the IOP Conference Series: Materials Science and Engineering*, Iasi, Romania, May 2019.

[6] H. Seliem, R. Shahidi, M. H. Ahmed, and M. S. Shehata, "Drone-based highway-VANET and DAS service," *IEEE Access*, vol. 6, pp. 20125–20137, 2018.

[7] G. Shah, R. Valiente, N. Gupta et al., "Real-time hardware-in-the-loop emulation framework for DSRC-based connected vehicle applications," 2019, https://arxiv.org/abs/1905.09267.

[8] D. J. Schmidt, *Vehicle Service Control*, Google Patents, 2019.

[9] U. Shaikh and N. Thalkar, "Vehicle communication systems: technology and review," in *Proceedings of the Conference on Technologies for Future Cities (CTFC)*, Mumbai, Maharashtra, March 2019.

[10] S. A. Ahmad, A. Hajisami, H. Krishnan, F. Ahmed-Zaid, and E. Moradi-Pari, "V2V system congestion control validation and performance," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 3, pp. 2102–2110, 2019.

[11] P. Sewalkar and J. Seitz, "Vehicle-to-pedestrian communication for vulnerable road users: survey, design considerations, and challenges," *Sensors*, vol. 19, no. 2, p. 358, 2019.

[12] S. Hayat, X. Liu, Y. Li, and Y. Zhou, "Comparative analysis of vanet's routing protocol classes: an overview of existing routing protocol classes and futuristic challenges," in *Proceedings of the 2019 IEEE 2nd International Conference on Electronics Technology (ICET)*, pp. 1–7, IEEE, Chengdu, China, May 2019.

[13] S. A. Ahmad and M. Shcherbakov, "A Survey on Routing Protocols in Vehicular Adhoc Networks," in *Proceedings of the 2018 9th International Conference on Information, Intelligence, Systems and Applications (IISA)*, Zakynthos, Greece, July 2018.

[14] M. Kumar, A. K. Nigam, and T. Sivakumar, "A survey on topology and position-based routing protocols in vehicular ad hoc network (VANET)," *International Journal on Future Revolution in Computer Science & Communication Engineering*, vol. 4, no. 2, pp. 432–440, 2018.

[15] I. Wahid, A. A. Ikram, M. Ahmad, S. Ali, and A. Ali, "State of the art routing protocols in VANETs: a review," *Procedia Computer Science*, vol. 130, pp. 689–694, 2018.

[16] J. Alves Junior and E. C. G. Wille, "Routing in vehicular ad hoc networks: main characteristics and tendencies," *Journal of Computer Networks and Communications*, vol. 2018, pp. 1–10, 2018.
[17] NHTSA, "Cybersecurity best practices for modern vehicles," 2019, https://www.nhtsa.gov/technology-innovation/vehicle-cybersecurity.
[18] T. A. Murshedi, X. Wang, H. Wang, and H. Cheng, "On-demand multipath routing protocols for mobile ad-hoc networks: a comparative survey," *International Journal of Future Computer and Communication*, vol. 5, no. 3, pp. 148–157, 2016.
[19] Y. Sun, L. Wu, S. Wu et al., "Attacks and countermeasures in the internet of vehicles," *Annals of Telecommunications*, vol. 72, no. 5-6, pp. 283–295, 2017.
[20] H. Hasrouny, A. E. Samhat, C. Bassil, and A. Laouiti, "VANet security challenges and solutions: a survey," *Vehicular Communications*, vol. 7, pp. 7–20, 2017.
[21] A. M. Makhlouf and M. Guizani, "SE-AOMDV: Secure and Efficient AOMDV Routing Protocol for Vehicular Communications," *International Journal of Information Security*, vol. 18, pp. 1–12, 2019.
[22] K. K. Rana, S. Tripathi, and R. S. Raw, "Analytical analysis of improved directional location added routing protocol for VANETS," *Wireless Personal Communications*, vol. 98, no. 2, pp. 2403–2426, 2018.
[23] S. Haider, G. Abbas, Z. H. Abbas, and T. Baker, "DABFS: a robust routing protocol for warning messages dissemination in VANETs," *Computer Communications*, vol. 147, pp. 21–34, 2019.
[24] K. N. Qureshi, A. H. Abdullah, and A. Altameem, "Road aware geographical routing protocol coupled with distance, direction and traffic density metrics for urban vehicular ad hoc networks," *Wireless Personal Communications*, vol. 92, no. 3, pp. 1251–1270, 2017.
[25] J. Wu, M. Fang, H. Li, and X. Li, "RSU-assisted traffic-aware routing based on reinforcement learning for urban VANETs," *IEEE Access*, vol. 8, pp. 5733–5748, 2020.
[26] H. Saleet, R. Langar, K. Naik, R. Boutaba, A. Nayak, and N. Goel, "Intersection-based geographical routing protocol for VANETs: a proposal and analysis," *IEEE Transactions on Vehicular Technology*, vol. 60, no. 9, pp. 4560–4574, 2011.
[27] M. A. Togou, A. Hafid, and L. Khoukhi, "Scrp: stable cds-based routing protocol for urban vehicular ad hoc networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 17, no. 5, pp. 1298–1307, 2016.
[28] S. More and U. Naik, "Analytical review and study on multipath routing protocols," *Control and Cybernetics*, vol. 49, no. 4, 2020.
[29] H.-C. Jang and H.-T. Huang, "Moving direction based greedy routing algorithm for VANET," in *Proceedings of the 2010 International Computer Symposium (ICS2010)*, Tainan, Taiwan, December 2010.
[30] Z. Ning, Y. Jung, Y. Jin, and K. Kim, "Route optimization for GPSR in VANET," in *Proceedings of the 2009 IEEE International Advance Computing Conference*, Patiala, India, March 2009.
[31] L. Hu, Z. Ding, and H. Shi, "An improved GPSR routing strategy in VANET," in *Proceedings of the 2012 8th International Conference on Wireless Communications, Networking and Mobile Computing*, Shanghai, China, September 2012.
[32] A. Z. Minn and M. Z. Oo, "Angle-aware greedy forwarding algorithm for vehicular ad hoc networks," *Journal of Computer Science*, vol. 2, no. 1, pp. 12–19, 2016.
[33] W. Lee, S. I. Chowdhury, G. Kee, W. Baek, and J. Pyun, "Velocity aware multipath distance vector routing protocol for high mobility over vehicular ad-hoc networks," in *Proceedings of the 2011 Fifth FTRA International Conference on Multimedia and Ubiquitous Engineering*, Crete, Greece, June 2011.
[34] H. Maowad and E. Shaaban, "Efficient routing protocol for Vehicular Ad hoc networks," in *Proceedings of the 2012 9th IEEE International Conference on Networking, Sensing and Control*, Beijing, China, April 2012.
[35] W. K. Lai, K.-T. Yang, and M.-C. Li, "Bus assisted connectionless routing protocol for metropolitan VANET," in *Proceedings of the 2011 Fifth International Conference on Genetic and Evolutionary Computing*, Kitakyushu, Japan, August 2011.
[36] Y. H. Ho, *CONNECTIONLESS APPROACHâ€ "A LOCALIZED SCHEME TO MOBILE AD HOC NETWORKS*, University of Central Florida, Orlando, Florida, 2009.
[37] W. K. Lai, C. K. Tai, and M. J. Wu, "CAME, connectionless approach for vehicular ad hoc networks in metropolitan environments," *Wireless Personal Communications*, vol. 91, no. 1, pp. 403–418, 2016.
[38] K. S. Atwal, A. Guleria, and M. Bassiouni, "SDN-based mobility management and QoS support for vehicular ad-hoc networks," in *Proceedings of the 2018 International Conference on Computing, Networking and Communications (ICNC)*, Maui, HI, USA, March 2018.
[39] H. Khelifi, L. Senlin, N. Boubakr, M. Hassine, F. Yasir, and H. Rasheed, "Named Data Networking in Vehicular Ad Hoc Networks: State-Of-The-Art and Challenges," *IEEE Communications Surveys & Tutorials*, vol. 22, 2019.
[40] M. Chowdhury, J. A. Khan, and L. Wang, "Smart Forwarding in NDN VANET," in *Proceedings of the 6th ACM Conference on Information-Centric Networking*, Macao, China, September 2019.
[41] Y. Li, X. Shi, A. Lindgren et al., "Context-aware data dissemination for icn-based vehicular ad hoc networks," *Information*, vol. 9, no. 11, p. 263, 2018.
[42] M. Chen, D. Ong Mau, Y. Zhang, T. Taleb, and V. C. M. Leung, "Vendnet: vehicular named data network," *Vehicular Communications*, vol. 1, no. 4, pp. 208–213, 2014.
[43] E. Kalogeiton, T. Kolonko, and T. Braun, "A topology-oblivious routing protocol for NDN-VANETs," *Annals of telecommunications*, vol. 73, no. 9-10, pp. 577–587, 2018.
[44] Z. Xia, P. Yu, and Y. Zhang, "Improving traffic information retrieval in VANET with NDN," in *Proceedings of the 2018 1st IEEE International Conference on Hot Information-Centric Networking (HotICN)*, Shenzhen, China, August 2018.
[45] S. Mastorakis, A. Afanasyev, and L. Zhang, "On the Evolution of ndnSIM," *ACM SIGCOMM - Computer Communication Review*, vol. 47, no. 3, pp. 19–33, 2017.
[46] L. Rui, H. Guo, H. Huang, R. Shi, and X. Qiu, "MUPF: multiple unicast path forwarding in content-centric VANETs," *Ad Hoc Networks*, vol. 81, pp. 211–225, 2018.
[47] J. Deng, S. Wang, and W. Wu, "Vehicular named data networking based on efficient incremental route update," in *Proceedings of the 2018 IEEE SmartWorld, Ubiquitous Intelligence & Computing, Advanced & Trusted Computing, Scalable Computing & Communications, Cloud & Big Data Computing, Internet of People and Smart City Innovation (SmartWorld/SCALCOM/UIC/ATC/CBDCom/IOP/SCI)*, Guangzhou, China, October 2018.
[48] M. Chowdhury, J. A. Khan, and L. Wang, "Smart Forwarding in NDN VANET," in *Proceedings of the 6th ACM Conference*

on Information-Centric Networking, Macao, China, September 2019.
[49] F. A. Silva, A. Boukerche, T. R. M. B. Silva, L. B. Ruiz, E. Cerqueira, and A. A. F. Loureiro, "Vehicular networks," *ACM Computing Surveys*, vol. 49, no. 1, pp. 1–29, 2016.
[50] F. A. Silva, A. Boukerche, T. R. M. B. Silva, E. Cerqueira, L. B. Ruiz, and A. A. F. Loureiro, "Information-driven software-defined vehicular networks: adapting flexible architecture to various scenarios," *IEEE Vehicular Technology Magazine*, vol. 14, no. 1, pp. 98–107, 2019.
[51] I. Ku, Y. Lu, M. Gerla, R. L. Gomes, F. Ongaro, and E. Cerqueira, "Towards software-defined VANET: architecture and services," in *Proceedings of the 2014 13th Annual Mediterranean Ad Hoc Networking Workshop (MED-HOC-NET)*, Piran, Slovenia, June 2014.
[52] K. S. Kalupahana Liyanage, M. Ma, and P. H. J. Chong, "Connectivity aware tribrid routing framework for a generalized software defined vehicular network," *Computer Networks*, vol. 152, pp. 167–177, 2019.
[53] M. Zhu, J. Cao, D. Pang, Z. He, and M. Xu, "SDN-based routing for efficient message propagation in VANET," in *International Conference on Wireless Algorithms, Systems, and Applications*Springer, Manhattan, NY, USA, 2015.
[54] K. L. K. Sudheera, M. Ma, and P. H. J. Chong, "Link stability based optimized routing framework for software defined vehicular networks," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 3, pp. 2934–2945, 2019.
[55] B. Masini, A. Bazzi, and A. Zanella, "A survey on the roadmap to mandate on board connectivity and enable V2V-based vehicular sensor networks," *Sensors*, vol. 18, no. 7, p. 2207, 2018.
[56] S. Ucar, S. C. Ergen, and O. Ozkasap, "Multihop-cluster-based IEEE 802.11p and LTE hybrid architecture for VANET safety message dissemination," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 4, pp. 2621–2636, 2016.
[57] H. Ghafoor and I. Koo, "CR-SDVN: a cognitive routing protocol for software-defined vehicular networks," *IEEE Sensors Journal*, vol. 18, no. 4, pp. 1761–1772, 2018.
[58] S. Sun, L. Gong, B. Rong, and K. Lu, "An intelligent SDN framework for 5G heterogeneous networks," *IEEE Communications Magazine*, vol. 53, no. 11, pp. 142–147, 2015.
[59] M. Chahal and S. Harit, "Network Selection and Data Dissemination in Heterogeneous Software-Defined Vehicular Network," *Computer Networks*, vol. 161, 2019.
[60] S. Bitam, A. Mellouk, and S. Zeadally, "VANET-cloud: a generic cloud computing model for vehicular Ad Hoc networks," *IEEE Wireless Communications*, vol. 22, no. 1, pp. 96–102, 2015.
[61] K. Bilal, O. Khalid, A. Erbad, and S. U. Khan, "Potentials, trends, and prospects in edge technologies: fog, cloudlet, mobile edge, and micro data centers," *Computer Networks*, vol. 130, pp. 94–120, 2018.
[62] N. Kumar, S. Zeadally, and J. J. P. C. Rodrigues, "Vehicular delay-tolerant networks for smart grid data management using mobile edge computing," *IEEE Communications Magazine*, vol. 54, no. 10, pp. 60–66, 2016.
[63] L. Tartarini, M. A. Marotta, E. Cerqueira et al., "Software-defined handover decision engine for heterogeneous cloud radio access networks," *Computer Communications*, vol. 115, pp. 21–34, 2018.
[64] J. C. Nobre, A. M. de Souza, D. Rosário et al., "Vehicular software-defined networking and fog computing: integration and design principles," *Ad Hoc Networks*, vol. 82, pp. 172–181, 2019.
[65] I. Wahid, A. U. A. Ikram, M. Ahmad, and F. Ullah, "An improved supervisory protocol for automatic selection of routing protocols in environment-aware vehicular ad hoc networks," *International Journal of Distributed Sensor Networks*, vol. 14, no. 11, Article ID 155014771881505, 2018.
[66] I. Wahid, F. Ullah, M. Ahmad et al., "Quality of service aware cluster routing in vehicular Ad Hoc Networks," *Computers, Materials & Continua*, vol. 67, no. 3, pp. 3949–3965, 2021.