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# Communication Solutions for Vehicle Ad-hoc Network in Smart Cities Environment: A Comprehensive Survey

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**Abstract**
In recent years, the explosive growth of multimedia applications and services has required further improvements in mobile systems to meet transfer speed requirements. Mobile Ad-hoc Network was formed in the 1970s. It is a set of mobile devices that have self-configuring capable to establish parameters to transmit data without relying on an pre-installed infrastructure systems. Today, MANET is strongly applied in many fields such as healthcare, military, smart agriculture, and disaster prevention. In the transportation area, in order to meet the unique characteristics of the vehicle network, such as movement pattern, high mobility with the support of RSUs, MANET has evolved into Vehicle Ad-hoc Networks, also called VANET. Due to the mobility of the nodes, like MANET, the performance of VANET is relatively low and depends on the communication technologies. Designing more flexible, reliable, and smarter routing protocols to improve VANET performance for smart urban is a significant challenge. In this study, we conduct a survey of communication solutions for VANET in recent years. The results indicated a common framework for designing VANET communication solutions based on three main approaches: *multi-metric*, *UAV/Cloud/Internet*, and *Intelligent*. Moreover, with each proposed solution, we also analyse to show the focus of the research and the results achieved. Finally, we discuss and point out possible future research directions. We hope that the research results in this work will be important guidelines for future research in the communication area for VANET.

**Keywords** Routing protocol · Smart cities · Quality of service · VANET

## 1 Introduction

According to Cisco forecasts, it is expected that over 70% of the global population will have mobile connectivity. The global mobile data traffic will increase eight times compared to 2018, with over 13.1 billion mobile devices are connected to the Internet network. In which multimedia traffic accounts for ¾ of the global network traffic [1]. Multimedia applications and services require the improvement of existing network systems. Therefore,

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designing more robust, believe, high-performance, and energy-efficient mobile networks is an urgent need. MANET (Mobile Ad-hoc Networks) was formed in the 1970s as a set of mobile devices capable of self-organising, self-configuring, and communicating with each other without relying on pre-existing infrastructures as fixed base stations [2]. Because of their flexibility in data setup and transmission, applied MANETs in many domains serve humanity as healthcare [3, 4], rescue, and disaster recovery [5, 6], intelligent transportation system [7, 8], retails [9], IoT ecosystems [10], and a series of different area, described in [11].

Along with the development of science and technology, intelligent transportation systems have been focused on research in recent times. A series of communication solutions between vehicles in the urban traffic environment have been proposed, as the traffic warning system [12–14], the emergency message transmission system [15, 16]. These solutions hypothesise that each vehicle is equipped with a radio transceiver, leading to vehicles communicating with each other without relying on base stations. As a result, each vehicle plays a role as a mobile ad-hoc network node, and form up Vehicle Ad-hoc Networks, also short called VANET.

Nowadays, the trend of urbanisation is happening globally. Large cities with tens of millions of people accommodate, such as New York-USA, Osaka-Japan, Beijing-China, etc. This led to the number of vehicles increasing suddenly and overloaded transport infrastructure. Traffic jams and traffic collisions often happen due to overcrowded vehicle traffic. The advent of 5th generation (5G) mobile networks in the early 2020s mark a truly digital era. 5G enables the delivery of services and applications with ultra-low latency and ultra-high throughput [18]. As a result, a series of smart traffic management applications for urban environments based on VANET have been proposed [8, 24].

Like MANET, the performance of the VANET depends on the size, communication model, and radio communication environment [17, 18]. In VANET, because mobile network nodes have to cooperate to transmit packets, the routing protocol has a vital role in enhancing network performance. Conventional routing protocols are proposed for MANET as AODV or DSR that use hops number as a routing metric are ineffective in the VANET environment [19].

In this study, aim found a common framework to solve the routing problem for VANET, we conducted a comprehensive survey of recently proposed routing solutions for urban-VANET applications in the period (2018–2021). Based on the surveyed results, we indicated the highlight and achieved results of each proposal. The rest of this study is organised as follows. In Sect. 2, we present an overview of the architecture and characteristics of VANET. Section 3 presents three typical routing methods for common ad-hoc networks, including Active, Reactive, and Heuristics. A survey of the proposed state-of-art routing protocols and algorithms for VANET is presented in Sect. 4. Discussions and future possible research directions are presented in Sect. 5, and Sect. 6 is Conclusion.

## 2 Architecture and Characteristics of VANET

The breakthrough improvements of ad-hoc networks and mobile communication technologies led to the formation of the VANET architecture. VANET is an evolutionary network type of MANET to respond to communication requirements between vehicles in transport systems. Therefore, VANET has some unique features and architecture compared to MANET, presented in Table 1.

**Table 1** Comparison of characteristics of VANET and MANET

| Property | VANET | MANET |
|---|---|---|
| Nodes | Vehicles (mobile network nodes) and RSU/Base station (pre-existing infrastructure) | Mobile devices (mobile) |
| Communication | V2V/V2I/I2I Device to device, One hop/multi-hop | One hop/multi-hop |
| Energy | Unlimited | Limited |
| Topology | Self-organising, Predictable pattern (road models), high mobility, frequent topology changes | Self-organising, Lower topology variations, unconstrained movement pattern |
| Dynamic nature | High Dynamic, frequent network joining and leaving nodes, correlated movements of mobile devices | Relatively stable nodes, uncorrelated movements of mobile devices |
| Nodes mobility | About [0–50] m/s | About [0–5] m/s |
| Signal reception | Poor signal reception (Radio obstacles, such as roadside buildings and interference of radio signal) | Good signal reception, no such obstacles |
| Connection life | Short; depends on road conditions, traffic lights, traffic jams | Relatively longer |
| Channel | Variable | Relatively stable |
| Sensors | High-Quality, GPS-assisted | Weak sensor |
| Infrastructure | RSU/Base Station-based | Without Infrastructure |

### 2.1 Characteristics

VANET is part of intelligent transportation systems. Specifically, vehicles need to communicate with each other to exchange information about current traffic conditions, roads, traffic light status, or control messages to optimise vehicle movement, incident control, set up priority routes in an emergency. Another point different from MANET. In VANET, mobile devices have higher speed movement and predictable roads pattern. Besides, vehicles can join/leave only the system at certain intersections [18]. As a result, the network structure is less changed than MANET. Because of large energy capacity storage vehicles, the energy efficiency problem no longer one of the most important in VANET.

In addition, routes in VANET are often pre-set and fixed, especially highways, so VANET is often supported by roadside units (RSUs) or base station systems existing installed along the roads. An important point for network nodes in VANET, vehicles are often equipped with GPS systems, so location information and speed movement can be easily provided for routing algorithms [24].

### 2.2 Architecture

The architecture of VANET has three main components, include (1) On-Board Units (OBU) devices mounted on each vehicle, (2) Roadside Units (RSUs) placed all along roads, and (3) the communication channel as presented in Fig. 1.

- OBU is a hardware device equipped with a radio antenna transceiver and joined to a processor. Besides, OBU also has a memory to allow information storage, Bluetooth interfaces, and GPS sensors. OBU devices have to support IEEE communication standards. Nowadays, the OBU device is a default standard and available is equipped for vehicles by producers [38].
- RSU is equipped with wired and wireless interfaces. They are generally positioned at high-density places such as intersections and gas stations along high roads. The RSUs are established to support communications between vehicle-to-vehicle, vehicle-to-Internet, and vice versa. One of the most important functions of RSUs enhance network performance and support QoS for VANET [43].
- Two main aspects characterise the wireless channels of VANET: (1) spectrum resource allocation, which is reserved for different VANET applications, and (2) divide bands according to international standards. Notably, in the United States and Europe, the spectrum is divided between channels of 10 MHz size. In Japan, channels are divided into downlink channels and uplink channels of 5 MHz size [30]. In reality, the wireless channel faces a series of reliability, signal attenuation, and path loss link.

### 2.3 Deployment Environment

Besides VANET architecture, another feature of VANET is the deployment environment. Actually, the VANET system could be deployed on a highway or urban.

In an *urban environment*, vehicles need to exchange information about streets, traffic jam status, and density traffic to give communication or control vehicles options.

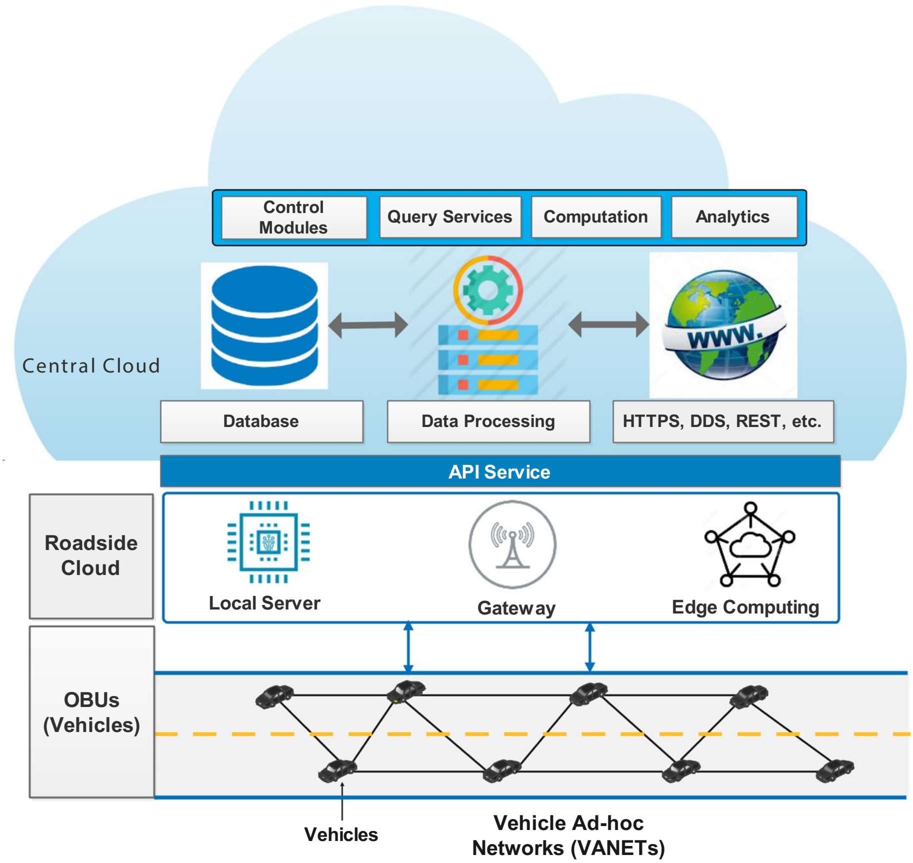


**Fig. 1** An illustration of cloud-assisted VANET architecture

Besides, the constrained vehicle speed inside cities and especially in small towns, commonly restricted to lower than 50 km per hour, lead to longer-lasting links between nodes. This is an important factor for improve performance systems and ensure QoS in real-time multimedia applications [8, 18, 24]. However, a disadvantage in an urban environment is buildings, crossroads, traffic lights representing obstacles for transmission, noise, and signal degradation.

In a *highway environment*, a significant advantage in this environment is usually fewer buildings, traffic lights, intersections, vehicle movements correlated. This results in a relatively stable network topology. Vehicular clustering is an adaptive technique to select data forwarding nodes. Besides, roadsides units or base stations often are established on the highway to support transfer data. The road infrastructure with its mobility patterns leads to the movements of predictable vehicles [56]. Therefore, the operating environment is one of many features making the unique VANET compared to MANET.

# 3 Traditional Routing Methods for VANET

Along with the developer history of mobile ad-hoc networks, IETF has standardised some typical routing protocols such as AODV, DSR, OLSR and DSDV. These protocols are fit and achieve high performance in MANET. However, with the unique features of VANET, these protocols have been refined to suitable and achieve high performance in VANET. In order to better understand how state-of-art routing protocols work for VANET, we analyse the operation principles of these typical routing protocols.

## 3.1 Proactive Routing Methods

Destination Sequenced Distance Vector (DSDV) [20] protocol is a proactive method-based routing protocol that uses hops number to making-decisions select the route. The proposed DSDV aims to solve the routing-loop problem by adding a sequence number field to the routing table. Unlike other proactive routing protocols, DSDV does not store a full topology map of the entire network. Instead, each node stores only one routing table to the known destination nodes. These routes are exchanged and updated periodically. When selecting a route, DSDV priority to the route which has the highest sequence number. In the case of equal sequential numbers, the DSDV will select the route with the lowest cost. Due to the periodical exchange and update of routing information, in a low mobile network environment as MANET, DSDV often causes waste of system resources and overload. However, DSDV promises a lot of contributions to high mobile VANET scenarios.

Link State Routing Protocol (OLSR) [21] OLSR is a proactive method-based routing protocol evolved from the link-state routing protocol for multi-hops. Network nodes are updated and exchanged routing information periodically. OLSR is proposed to reduce the overload caused by broadcast packets. First, network nodes send broadcast Hello packets in two hops to determine neighbouring nodes. Then, these nodes elect the MPR node (Multi-Point Relay). MPRs act as the centre relay nodes. Only these nodes capable of forwarding broadcast packets. As a result, the broadcast packet number and the control packet size decreases. In a low-mobility network environment, OLSR often consumes a lot of network resources. However, the performance of OLSR rather well in the high density and mobile network environment.

## 3.2 On-Demand Routing Methods

AODV [22] and DSR [23] are typical on-demand-based routing protocols for MANET. They operate based on the principle only when the source node needs to be transmitted data; it performs the discovery procedure and finds routes to the destination node. The route discovery procedure is started by the source that sends broadcast RREQ packets, as presented in Fig. 2. Then, RREQs are forwarded to the destination node through the intermediate nodes. The destination node or the intermediate node (which knows information about the route to the destination node) sends unicast the RREP packet to the source node, as shown in Fig. 3. When the source node is received the RREP packet, the route is established, and data can be transmitted. In addition, these protocols also have route maintenance procedures related to the error routes through the RERR packet.

The two main features of AODV are the route establishing method and the sequence number property. AODV does not pre-determine a route to transmit data from source to destination. Instead, the next hop is decided by each node when the data arrives based on

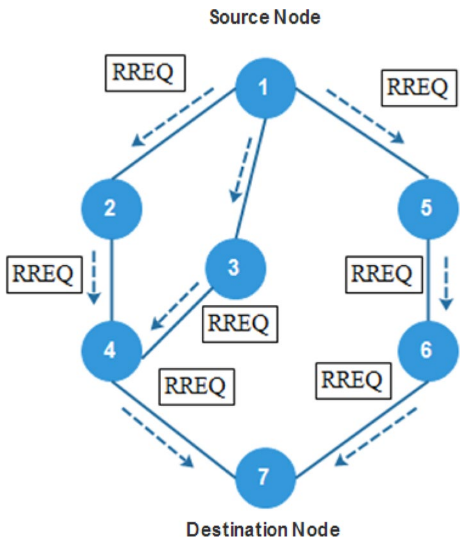


**Fig. 2** RREQ packets send process

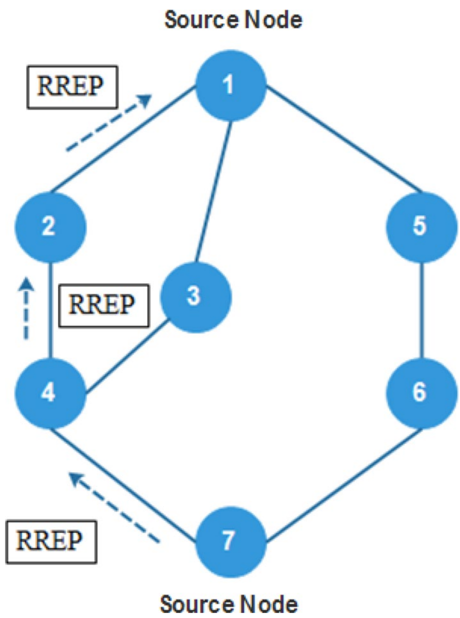


**Fig. 3** RREP packet send process

the routing information obtained by that node. Besides, AODV also uses the sequence number attribute to determine the time of the packet and to avoid routing-loop. Meanwhile, the main feature of DSR is the method of determining the route from the source node. DSR based on the information returned by the RREP packet to determine the best route. Therefore, RREQ and RREP packets must contain information about the addresses of the intermediate nodes. While AODV does not store any routing table, DSR maintains a cache of the routes and uses routes in memory until they are invalid. In the low-mobility MANET, on-demand routing protocols have energy-efficient and performance well. However, they can be improved to suitable in high mobility environment and has unique characteristics as VANET.

Although the above protocols have been standardised into routing protocols for common MANET, they support well the features of ad-hoc network architectures such as self-organisation, self-configuration, and mobility. They also have route discovery and maintenance procedures, which are used to adapt to frequently broken links. In a performance comparison, AODV and DSR have the packet delivery ratio reached over 90%, while the DSR performance is highest for small size networks. OLSR and DSDV often consume a lot of network resources in low-mobility MANET scenarios. However, with the unique characteristics of VANET, more flexible, efficient and suitable routing protocols for VANET scenarios need to be more further studied and evaluated.

### 3.3 Heuristics-Based Optimisation Routing Methods

Ant/Bee colony optimisation (ACO/BCO) algorithms are nature-inspired shown a great tendency to solve complex problems. ACOs/BCOs are swarm intelligence (SI) based techniques inspired by the collective behaviour of different animals as ants, bees, birds, insects, flies, and other species. Agents in a swarm are the result of indirect local communications achieved based on the pheromone [24–28].

Pheromone actually is a volatile chemical substance deposited by the ants/bees to influence other following ants/bees in a swarm. When an animal moves from its nest to search for food, it leaves a trail of pheromone behind it, which is followed by other animals.

Two important characteristics of pheromone are known as evaporation and concentration. When a path is selected by frequently by several animals as ants/bees, the concentration of pheromone becomes increases on that path. Therefore, the path with a higher pheromone level led to a higher selected probability. Meanwhile, a without selected path frequently led to the decreased pheromone (pheromone evaporation).

One important feature of shortest path discovery in ant/bee colony metaheuristics is the random behaviour demonstrated by a few ants/bees. In the food searching process, an ant/bee can also select a path randomly, ignoring paths that even have higher pheromone concentrations. It means that animals might not follow the pheromone trail (concentration)

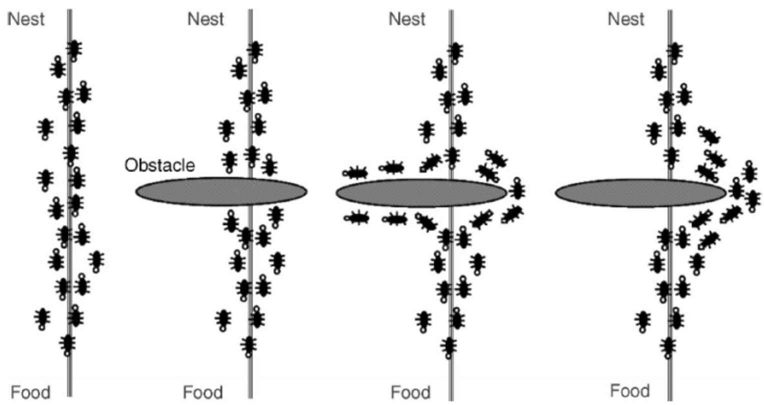


**Fig. 4** Ant colony searching for the food source

all the time. Instead, they may select any path based on their local behaviour or heuristics. This local behaviour is a method to escape out of local minima as well as an important strategy to achieve an optimal path. Figure 4 presents an illustration of the experiment results performed with the Argentine ant colony [29].

## 4 Survey of Recent Routing Protocols for VANET

To clarify the state-of-art approaches and studies aim to enhance system performance and support QoS for VANETs. We surveyed proposals published in the recent four years, period 2018–2021, on the IEEE Xplore digital library database. We divided proposals into three categories based on their approach. For each proposal, we also detailed analyse, point out the focus of each proposal and achieved results. Survey results are summarised in Table 2.

In [30], Xia et al. (2018) proposed a new routing protocol for urban VANET, called GTLQR (Greedy Traffic Light and Queue aware Routing). The focus of this work considers metrics such as the street connectivity, channel quality, relative distance, and queuing delay to limit the packet loss ratio caused by vehicle clustering at the intersection and balance the traffic load among vehicles. Simulation results indicated that the proposed protocol improved outperform compared with TLRC and GLSR-L protocols in terms of delay time and packet delivery ratio in various mobility scenarios.

In [31], Tian et al. (2018) proposed a routing protocol for VANET to adapt in a highly dynamic environment, called URAS (Unicast Routing protocol based on Attractor Selecting). The focus of this work proposes a multiattribute decision-making strategy to reduce the candidate routes number for the next-hop selection. Simulation results indicated that the URAS improved significantly in delay time, packet delivery ratio, and congestion than traditional routing protocols.

In [32], Yang et al. (2018) proposed a GPRS-based improved routing protocol, called MM-GPSR routing protocol (Maxduration-Minangle GPSR) for high-velocity VANET. This work proposed a method to determine the stability of links. Then, the next hop will be selected on the link, which has maximum stability. Besides, this protocol also proposed the minimum angle metric by integrating the position of the neighbourhood node into selecting the optimal next hop when the greedy forwarding mechanism fails. Simulation results indicated that the proposed protocol improves significantly in end-to-end delay, throughput, and packet loss ratio than the GPRS protocol.

In [33], Lou et al. (2018) introduced a schema to control access to support security-aware for Cloud-assisted VANETs, called the MA-CP-ABE scheme. The focus of this work proposes a trusted central authority is employed to manage attributes and distribute keys based on multi-authority. They introduced a secure and revocable access control scheme for vehicular cloud computing. Experiment results indicated the efficiency of the proposed solution compared to different existing solutions.

In [34], Goudarzi et al. (2019) proposed a traffic-aware position-based routing protocol, improved from the existing GSR routing protocol, called efficient GSR for VANET in urban environments. The focus of this work proposal each vehicle will be equipped with a digital map that has streets. Aim to find the optimal route; vehicles will exchange small packets, called ants, to collect information streets, then these streets will have a weight. Finally, an ant colony optimisation routing algorithm will be used to determine the optimal route. Simulation results indicated that the proposed protocol improved in terms of packet delivery ratio, routing control overhead and end-to-end delay compared with other routing

**Table 2** Compare of recent routing protocols for VANET, period (2018–2021)

| References | Proposal | Approach | Focus of research | Results |
|---|---|---|---|---|
| [30] | GTLQR protocol, 2018 | Multi-Metric | Take connectivity, channel quality, relative distance, and queuing delay metrics into account cost function to improve the packet delivery ratio VANET | Improve in terms of performance in various mobility scenarios compared to TLRC and GLSR-L protocols for urban VANET |
| [31] | URAS protocol, 2018 | Multi-Metric | Based on multi-attribute decision-making strategy to reduce the candidate routes number | Improve performance and congestion compared to traditional routing protocols in high mobility VANET |
| [32] | MM-GPSR protocol, 2018 | Multi-Metric | Improved based on GPRS routing protocol<br>Routing decision-making based on thestability of links<br>Uses the minimum angle metric by take the position of neighbourhood nodes into account to select the optimal next hop when the greedy forwarding mechanism fails | Improve in terms of end-to-end delay, throughput, and packet loss ratio compared with the GPRS protocol in high mobility VANET |
| [33] | MA-CP-ABE scheme, 2018 | Cloud-assisted | Improve a traditional ciphertext-policy attribute-based encryption through the use of a secure and revocable access control scheme for Cloud-assisted VANETs to obtain multi-authority CP-ABE schema | Improve communication cost and computational complexity |
| [34] | Efficient GSR protocol, 2019 | Intelligence | Each vehicle is equipped with a digital map<br>Use the ant colony optimisation routing lgorithm to select the optimal route | Improve in terms of performance compared with other routing protocols in high mobility VANET scenarios (about 70 km/h) |
| [35] | DGGR protocol, 2019 | Multi-Metric | Divide the road map into Grid Zones<br>Use the road weight evaluation algorithm (RWE) to select the best route of each Grid Zone to transfer data | Improve in terms of delay time, packet delivery ratio compared to traditional routing protocol in other density and mobility VANET scenarios |
| [36] | PA-GPSR protocol, 2019 | Multi-Metric | Improve from an existing GPRS routing protocol<br>Additional extension tables to select the optimal route<br>Propose avoiding routing loops algorithm | Improve performance compared to the existing GPRS-based routing algorithm |

**Table 2** (continued)

| References | Proposal | Approach | Focus of research | Results |
|---|---|---|---|---|
| [37] | Centralised Routing Schema, 2019 | Intelligence | Define an AI and SDN-based VANET | Improve delay time and other performance metrics compared to other existing routing protocols in heterogeneous VANET scenarios |
| | | | Propose a mobility prediction algorithm of vehicles based on AI to estimate packet transmission probability and delay | |
| | | | Based on the entire system structure, the SDN controller will determine the best route | |
| [38] | Member-centric protocols, 2019 | Multi-Metric | Combine OMR routing protocol and several routing strategies | Improve the reliability of the route and load balancing in the whole network in high mobility VANET scenarios |
| | | | Combine RMCM routing protocol and the merged strategy | |
| [39] | ProMRP protocol, 2019 | Multi-Metric | Use an estimated algorithm to determine the delivery probability of a packet to the destination node based on multi-metrics | Improve performance compared to recent routing protocols in other density and mobility scenarios for urban VANET |
| | | | Evolve ProMRP protocol to EProMRP protocol by proposes an estimated algorithm for the current position of nodes | |
| [40] | IPS schema, 2019 | Internet-assisted | Use a collaborator schema based on incentive and punishment mechanism | Improve performance metrics |
| [41] | PASRP protocol, 2020 | Multi-Metric | Use the spider-web transmission model | Improve in terms of performance compared to existing routing methods to transfer emergency data in urban VANET scenarios |
| | | | Each vehicle is equipped with a digital map | |
| [42] | Onion-based anonymous protocol, 2020 | Multi-Metric | Use technical the location-based dynamic relay group (mobile nodes from groups around specific locations to act as cryptographic onion relays | Improve in terms of performance compared to existing onion-based routing protocol in high mobility VANET |

**Table 2** (continued)

| References | Proposal | Approach | Focus of research | Results |
|---|---|---|---|---|
| [43] | QTAR protocol, 2020 | Intelligence | QTAR operate based on three methods:<br>QGGF (Q-Greedy Geographical Forwarding)<br>R2R Q-learning (Q-learning occurs between RSU)<br>SCF (Store-Carry-Forward) | Improve packet delivery ratio, end-to-end delay (over 46%) compared to existing routing protocols in mobility urban VANET scenarios |
| [44] | BTA-GRP protocol, 2020 | Multi-Metric | Take traffic density, distance and direction metrics into account routing cost function to select the fit route | Improve packet delivery ratio, delay time, routing overhead compared with existing routing protocols in other mobility and density scenarios in smart cities |
| [45] | NDN protocol, 2020 | Intelligence | Combine Named Data Network into VANET<br>Routing decision-making based on Bayesian theory according to current network conditions<br>Use a back-off mechanism aim limit the broadcast storm | Improve interest packet redundancy compared with existing routing algorithms in NDN-VANET |
| [46] | IDR protocol, 2020 | Intelligence | Propose Intersection Vehicle Fog (IVF) model which using fuzzy logic to analyse the current traffic conditions<br>Uses the ant colony optimisation algorithm to select the optimal route | Improve performance metrics compared with traditional routing protocols in urban VANET |
| [47] | PPR protocol, 2020 | Intelligence | Use a packet reception probability model;<br>Routing decision-making based on multi-objective optimisation problem to find a link with the highest packet reception probability | Improve delay time, packet delivery ratio, and throughput compared to the existing routing protocol for three-dimensional VANET scenarios |

**Table 2** (continued)

| References | Proposal | Approach | Focus of research | Results |
|---|---|---|---|---|
| [48] | SURFER protocol, 2020 | Intelligence & Internet-assisted | Improve from the existing ROAMER routing protocol<br>Use SDN (Software-Defined Networking) architecture and a Blockchain system within roadside units or whole IoV | Improve significantly in terms of delay time and packet delivery ratio, routing overhead compared with recent other IoV routing protocols in other mobility and density IoV scenarios |
| [49] | CACA protocol, 2020 | Multi-metric | Propose the reliability-based routing cost function uses two metrics: signal strength and the mobility level of a node to find longer-lasting lifetime routes | Improve performance metrics compared with other traditional routing algorithms |
| [50] | BRT protocol, 2020 | Intelligence | Use bus systems as intermediate nodes. This routing algorithm includes two-stage:<br>Learning process: need only perform one time to build routes and expected delay<br>Routing process: forward packets through the bus base station towards an RSU or other vehicles based on pre-learned routing information | Improve performance metrics compared to other existing routing algorithms |
| [51] | KPND protocol, 2020 | Multi-metric | Use a mobility prediction algorithm based on each vehicle's temporal and space mobility characteristics according to Kalman theory and a threshold triggered<br>Based on this threshold value, mobile nodes will activate the update procedure to update parameters to the prediction model | Improve neighbour discovery rate compared with other common algorithms such as HP-AODV, ARH, and ROMSG in high mobility VANET scenarios |
| [52] | MHVA schema, 2020 | Cloud-assisted | Use a flexibly offloading schema between vehicles to support mobile edge computing | Improve performance metrics and reduce service response delay |
| [53] | MRS-based schema, 2020 | Cloud-assisted | Use a real-time schema to traffic data aggregation for vehicles cloud | Enhance security and improve computing & communication costs |

**Table 2** (continued)

| References | Proposal | Approach | Focus of research | Results |
|---|---|---|---|---|
| [54] | VRU routing protocol, 2021 | UAV-assisted | Use AI algorithms with UAV-assisted for urban VANET. Include two sub-protocols to routing data and support detection of malicious vehicles:*VRU_vu* protocol to routing packets between vehicles with the UAV-assisted, and (2) the *VRU_u* to routing packets between UAVs | Improve packet delivery ratio, delay time, routing overhead, malicious detection ratio compared to existing routing protocols in UAV-assisted urban VANET scenarios |
| [55] | VEC framework, 2021 | Cloud-assisted | Use outside parked cars as edge computing servers | Improve offloading services, highlight in large huge task request number scenarios |

protocols based on ant colony optimisation. In the case at the velocity of the vehicle about 70 km/h, the packet delivery ratio improves over 10%.

In [35], Chen et al. (2019) proposed a new delay-aware routing protocol called DGGR (Delay-aware Grid-based Geographic Routing) for urban VANET. The focus of this work uses a road weight evaluation algorithm (RWE), then each road will be assigned a weight. Besides, this solution also divides the road map into Grid Zones (GZs), then in each GZs, the best route is determined by the RWE algorithm. Finally, based on the position of the destination vehicle, data will be transfer between GZs. Simulation results show that the proposed protocol improves in terms of delay time, packet delivery ratio compared with traditional routing protocol in other density and mobility scenarios.

In [36], Silva et al. (2019) proposed a new routing strategy named PA-GPSR (Path Aware GPSR) aim improve the overall performance of VANET. The proposed protocol improved from an existing well-known GPRS routing protocol. The focus of this work proposes additional extension tables to select the optimal route. Besides, this work also proposes avoiding routing loops algorithm. Simulation results on SUMO and NS3 simulation software indicated that the proposed algorithm improves outperforms in packet delivery ratio, delay time, and other performance metrics than the existing routing algorithm based on GPRS in other density and mobility scenarios.

In [37], Tang et al. (2019) proposed a centralised routing algorithm based on mobility prediction to improve overall heterogeneous VANET performance. This study proposed include (1) define a heterogeneous VANET is VANET assisted by an AI (Artificial Intelligence) powered SDN (Software-Defined Network) controller; (2) a new mobility prediction method of the vehicles based on AI network to estimate successful packet transmission probability and end-to-end delay; (3) Based on information the whole structure system, roadside units (RSU), and base station, the SDN controller will compute and determine the best route for switches. Simulation results demonstrated the proposed protocol outperforms in terms of delay time and other performance metrics compared to other existing routing protocols in varying mobility and density scenarios.

In [38], Huang et al. (2019) proposed member-centric routing protocols for transfer multimedia data in high mobility VANET. Specifically, this work proposed include (1) combine OMR routing protocol (On-demand Member-centric Routing) and severalty routing strategy; (2) combine RMCM routing protocol (Reactive Member-Centric Routing) and the merged strategy aim improve the reliability of the route and load balancing in whole network. Simulation results indicated that the proposed member-centric routing protocols aim improve the reliability of the route and load balancing in the whole network.

In [39], Cárdenas et al. (2019) proposed a new novel multi-metric routing protocol, called ProMRP (Probabilistic Multimetric Routing Protocol) for smart traffic systems in the urban environment. The focus of this work proposes an estimates function to determine the probability of successfully deliver a packet to a destination based on four metrics, include distance to destination, the position, available bandwidth and density of nodes. Besides, this work also evolves ProMRP protocol to EProMRP protocol by proposing an estimate algorithm for nodes' current position instead of using the last updated position from the beacon packet. Simulation results show that proposed protocols improve significantly in delay time and packet loss ratio compared with recent routing protocols in other density and mobility scenarios for urban VANET.

In [40], Rehman et al. (2019) introduced a new collaborator schema based on incentive and punishment mechanism between vehicles for Internet-assisted VANETs, called IPS schema. This schema operates rely on the principle of clustering. The nodes of each cluster elect a head node based on the weight of the vehicle. The reputation score of the node could be increased through active data transmission. Opposite, the selfish nodes that do not forward data will be punished. The schema aims to limit the selfish behaviours of some nodes on the Internet of Vehicles. Experiment results demonstrated the IPS schema enhanced in terms of delay, cost, overhead, and delivery ratio compared to other existing schemas.

In [41], Liu et al. (2020) proposed a new routing protocol to transfer emergency data rapid and reliable between vehicles in urban VANET, called PASRP (Parking-Area-assisted Spider-web Routing Protocol). The focus of this work proposes a spider-web transmission model based on the parking area. Besides, this work proposed each vehicle is equipped with a digital map to include a geographic information system. This protocol also uses request-spider, and confirm-spider control packets to obtained routes information aim determined the route has minimum delay time. Simulation results indicated that the proposed protocol improved significantly in packet delivery ratio, delay time, and routing overhead compared to existing routing methods in the urban environment.

In [42], Sayad Haghighi et al. (2020) proposed a novel onion-based anonymous routing protocol for highly mobile VANET aim anonymity source vehicle, destination vehicle, and route. The focus of this work proposed the concept of location-based dynamic relay groups, where mobile nodes from groups around specific locations act as cryptographic onion relays. Simulation results on SUMO simulation software show that the proposed protocol improve significantly in terms of delivery ratio, delay and number of retransmissions compared with the existing naive onion routing protocol.

In [43], Wu et al. (2020) proposed a new routing protocol, called QTAR (RSU-assisted Q-learning-based Traffic-Aware Routing) for mobility VANET in the urban environment. This routing protocol integrates the advantages of both methods, include geographic routing and static road map routing. QTAR learns the road traffic information based on the Q-learning algorithm. QTAR operate based on three methods: (1) QGGF (Q-Greedy Geographical Forwarding) is to reduce the delay time; (2) R2R Q-learning (Q-learning occurs between RSU units) to forward packets at each intermediate intersection; (3) SCF (Store-Carry-Forward) is used to reduce the packet loss ratio. Simulation results show that the proposed protocol improves significantly in terms of packet delivery ratio, end-to-end delay compared with existing routing protocols in other mobility and traffic scenarios. In some low mobility scenarios, QTAR improves over 46% in terms of end-to-end delay.

In [44], Din et al. (2020) proposed a new routing protocol, called BTA-GRP (Beaconless Traffic-Aware Geographical Routing Protocol) for VANET in intelligent cities. This protocol is improved from geographic routing protocols. This study integrated metrics include traffic density, distance and direction into the routing cost function to select a fit route. Simulation results demonstrated that the proposed protocol improved packet delivery ratio, delay time, and routing overhead compared with existing routing protocols in other mobility and density scenarios in smart cities.

In [45], Guo et al. (2020) proposed a new routing schema to combine NDN (Named Data Network) into VANET forming NDN-VANET network architecture, called BRFD scheme (Bayesian-based Receiver Forwarding Decision). In this study, the mobile nodes make receiver-forwarding decisions based on Bayesian decision theory according to current network conditions. Besides, this schema also uses a back-off mechanism aim limit the broadcast storm issue appear by interest packets in NDN-VANET. Simulation results indicated that the proposed routing schema reduced the packet redundancy significantly compared with existing routing algorithms.

In [46], Sun et al. (2020) proposed a new routing solution for communication in urban VANET, include a new routing strategy, called IDR (Intersection-based Distributed

Routing) and a new model, called IVF (Intersection Vehicle Fog). The IVFs use fuzzy logic to analyse the traffic conditions on adjacent routes by proactively establishing multi-hop links with neighbourhood intersections. To determine the optimal route, IDR uses the ant colony optimisation algorithm. Simulation results and mathematical analyses show that the proposed solution improves performance metrics compared with traditional routing protocols.

In [47], Xu et al. (2020) proposed a new routing protocol for three-dimensional VANET scenarios, called PPR (Packet reception Probability-based Reliable routing), to improve the link reliability. The focus of this work proposes a packet reception probability model, then the routing decision-making based on the multi-objective optimisation problem to find a link with the highest packet reception probability. Simulation results indicated that the proposed protocol improved significantly in delay time, packet delivery ratio, and throughput compared to existing routing protocols.

In [48], Mershad et al. (2020) proposed the SURFER routing protocol (Secure SDN-based Routing Protocol for the Internet of Vehicles), improved from the existing ROAMER routing protocol for IoV (Internet of Vehicles). This work uses SDN (Software-Defined Networking) architecture and a Blockchain system within roadside units or whole IoV to route packets securely and efficiently. Simulation results indicated that the SURFER routing protocol improved significantly in terms of delay time and packet delivery ratio, routing overhead compared with recent other IoV routing protocols in other mobility and density scenarios.

In [49], Al-Kharasani et al. (2020) proposed an improved routing algorithm from the well-known OLSR routing protocol, called CACA (Cluster-based Adept Cooperative Algorithm). The focus of this work proposes a cluster-based QoS algorithm by each network node to estimate the reliability of routes based on a reliability-based cost function for longer-lasting lifetime routes. The reliability-based cost function uses two metrics: signal strength and the mobility level of a node aim minimum control packets size and improve routing tables' re-calculation process. Simulation results indicated that the proposed routing algorithm improved performance metrics significantly compared with other traditional routing algorithms.

In [50], Chaib et al. (2020) proposed a new routing algorithm based on bus rapid transit systems that aim to improve VANET performance, called BRT (Bus-based Routing Technique). The focus of this work proposes bus systems that predictable mobility role intermediate network nodes to transfer data from source vehicle to roadside units (RSUs) or destination vehicles. The proposed algorithm includes two stages, (1) the learning process need only perform one time to build routes in routing tables and expected time delay, and (2) the routing packets based on exploits the pre-learned periods to forward packets through the bus base station towards an RSU or destination vehicle. Experiment results demonstrated that the proposed algorithm improved performance metrics significantly compared to other existing routing algorithms.

In [51], Liu et al. (2020) proposed a new algorithm based on Kalman prediction, called KPND, to fast discover neighbours in the route discovery procedure for high mobility VANET. The focus of this work proposes a mobility prediction algorithm based on the temporal and space mobility characteristics of each vehicle according to Kalman theory. Besides, this work also presented a threshold triggered. Based on this threshold value, mobile nodes will activate the update procedure to update parameters to the prediction model. Simulation results indicated that the proposed algorithm improved neighbour discovery rate compared with other common algorithms such as HP-AODV, ARH, and ROMSG.

Edge computing is an emerging concept that provides minimises service response times for real-time applications. One of the key challenges of edge computing is offloading computing. To solve this problem, in [52], Deng et al. (2020) proposed a flexibly offloading schema between vehicles to support mobile edge computing (MEC), called MHVA schema. Instead of only vehicles in the range of MEC server jointly computation offloading, this schema uses the full vehicle ad-hoc networks to support the computation offloading. Experiment results demonstrated the proposed schema decreased offloading delay and cost compared to other existing schemas in different scenarios.

Although vehicles cloud provides unprecedented capabilities for VANET, such as powerful edge computing, reduced service response time, one of the challenges of this problem is data combination. The obtained data is incorrect could be led to traffic collisions and affect human life. To solve this problem, in [53], Shen et al. (2020) [53] proposed a new real-time schema to traffic data aggregation for vehicles cloud. Specifically, they recover original traffic data based on verifying the validity of the vehicle signature. Experiment results demonstrated the proposed schema enhanced security-aware, private preservation, limited attacks, computing and communication costs compared to other existing schemas.

In [54], Fatemidokht et al. (2021) proposed a new Efficient and Secure based on AI algorithms with UAV-assisted for urban VANET, called *VRU*. The focus of this work presented two sub-protocols to routing data and support detection of malicious vehicles, include (1) the *VRU_vu* protocol to routing packets between vehicles with the UAV-assisted, and (2) the *VRU_u* to routing packets between UAVs. This work also established a simulation system for performance evaluation of the proposed protocol. Simulation results show that the *VRU* protocol improved packet delivery ratio significantly, delay time, routing overhead, malicious detection ratio compared to existing routing protocols.

Aim to solve limited resource problems in edge computing-based VANETs, in [55], Ma et al. (2021) proposed an edge computing solution rely on outside parked cars, called the VEC framework. The focus of this work presented includes: (1) each parked car plays a role as an edge computing server; (2) a new task scheduling schema to resource assignment management and computing edge server selection, and (3) a local task scheduling policy allocates suitable tasks to parked vehicles. Experiment results indicated the efficiency of the proposed solution compared to other existing solutions.

## 5 Discussion and Future Research Directions

Surveying the above studies have shown that VANET is expected to play an important role in the future of the Internet. Like MANET, although VANET performance is relatively low, with its flexible mobility and ad-hoc connectivity, VANET will be increasingly applied in many fields, especially for intelligent traffic systems (ITS) or IoT ecosystems. The survey results also have shown some exciting results as follows:

- 100% of studies hypothesis that each vehicle is equipped with digital maps (GPS system).
- 100% of the studies use simulation software for the performance evaluation of the proposed solution. The popular simulation software includes NS2, OPNET, and SUMO, over 90% of the study use NS2 network simulation software.
- 100% of the studies use common performance metrics such as packet delivery ratio, end-to-end delay, average throughput, routing overhead, QoS for efficiency evaluation of the

proposal. The two most commonly used parameters are the packet delivery ratio and end-to-end delay (over 95%).

- The studies often performance evaluations compare to similar solutions, the same routing method or some traditional routing protocols as outlined in Sect. 2. These studies often evaluate performance metrics in terms of throughput, latency, and packet delivery ratio compared to similar solutions, the same routing method, or some traditional routing protocols as outlined in Sect. 2. Besides, based on the proposed solutions such as security-aware, saving energy, or support QoS, these studies are also evaluated on the respective aspects.

The survey results also show that many studies have been proposed to improve the ability and capability of VANET [30–50], in which potential solutions are emerging, such as multi-metric, load balancing, Internet / UAV-assisted VANET, based on AI / SDN and Blockchain systems. Simulation results show that the proposed solutions have improved performance, QoS support, energy efficiency or security-aware metrics compared to some existing protocols. However, there are some limited issues that need to be further studied in these directions, specifically as follows:

(1) In the *multi-metric approach*, traditional routing protocols use the smallest hops number. However, recent research results have demonstrated that using only hops numbers will not find the optimal route. Therefore, it is necessary to incorporate metrics such as hops number and other performance parameters such as delay, length queue, and link quality into the routing cost function. In order to get more routing information, these proposals often add fields to the header of control packets, resulting in a larger routing packets size. As a result, the system consumed more energy. In our opinion, there should be studies and evaluations on the effectiveness of this solution.

(2) In the *Internet/UVA/Cloud-assisted VANET approach*. In order to expand the ability and capability of MANET, recent proposals have proposed solutions to integrate VANET and Internet/UAV/Cloud, forming Internet/UAV/Cloud-assisted VANET architectures. The advantage of this solution is to expand working space and enhance performance, network lifetime, QoS support of VANET by offloading energy-consuming services to Internet/UAV/Cloud. However, the problem of disconnection between Internet/UAV/Cloud and VANET will occur frequently. As a result, the system will consume more energy for reset operations. We believe that this solution will be the key to solving the problems of VANET in the future, but management problems of the connection between Internet/UAV/Cloud and VANET should be further explored.

(3) In the *Intelligence-based approach* such as AI/SDN and Blockchain systems. In order to establish optimal communication solutions for VANET, recent studies used ant colonies/bee/fuzzy logic algorithms to solve the multi-object optimal routing problem. Besides aiming to establish security-aware routing algorithms, studies also propose anonymous routing solutions based on blockchain systems. However, a highlight limitation of all research proposes an integration between VANET and the pre-established fixed network infrastructure, called roadside units (RSU), and base stations. This issue only suitable in certain scenarios, such as VANET applications for highway systems.

## 6 Conclusion

Survey results demonstrated that inter-vehicle communication in smart transportation systems is one of the most important applications of VANET for humanity. The research direction of routing solutions for VANET is feasible, urgent, topical, and attracts great attention from both communities of academic researchers and industrial. In this study, we surveyed state-of-art routing solutions for the inter-vehicle communication problem in smart cities. The survey results indicated that to enhance the ability and capacity of VANET, the proposals focus on three main directions, including (1) *multi-metric*, (2) *Internet/UAV/Cloud*-assisted VANET and (3) *Intelligence*-based VANET. In addition, we analysed the main contributions of each solution as well as pointed out promising research directions in the future. We hope that the results of this study will be important instructions for future research of the communication area in VANET. In the future, we will focus on researching and proposes more smart and flexible routing protocols for intelligent traffic systems based on the Internet of Things and edge computing.

## Appendix

See Table 3.

**Table 3** Acronyms used in the survey and definations

| Acronym | Definition | Acronym | Definition |
|---|---|---|---|
| ACO/BCO | Ant/Bee colony optimisation | ITS | Intelligent traffic system |
| AI | Artificial intelligence | M2M | Mechanism to mechanism |
| AODV | Ad-hoc on demand distance vertor | MANET | Mobile Ad hoc networks |
| API | Application programming interface | NS2 | Network simulator version 2 |
| D2D | Device to device | OLSR | Link state routing protocol |
| DDoS | Distributed denial of service | OPNET | Optimised network engineering tools |
| DoS | Denial of service | QoS | Quality of service |
| DSDV | Destination sequenced distance vector | RSU | Roadside unit |
| DSR | Dynamic source routing | SaaS | Software as a service |
| GIS | Geographic information systems | SDN | Software-defined networking |
| GPRS | General packet radio service | SUMO | Simulation of urban mobility |
| GPS | Global positioning system | UAV | Unmanned aerial vehicle |
| IaaS | Infrastructure as a service | V2I | Vehicle to infrastructure |
| IoT | Internet of things | V2V | Vehicle to Vehicle |
| IoV | Internet of vehicles | VANET | Vehicular Ad hoc networks |

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**Declaration**

**Conflict of interest** The authors declare no conflict of interest.

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