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Recent Topology-based Routing Approaches in VANETs: A Review

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Abstract—**Due to increasing both safety and efficiency of the traffic, Vehicular Ad Hoc Network (VANET) is a promising technology of Intelligent Transport Systems (ITS). Unique characteristics of VANETs including high mobility and strict delay constraints, require new routing solutions specific to these networks to be proposed. As one of those solutions, topology-based routing approaches aim to find the shortest path by managing routing tables. In this paper, recent topology-based routing approaches for VANETs are investigated in detail. Proactive, reactive and hybrid solutions are compared with respect to their advantages, disadvantages, updating procedures and network sizes. This paper will shed light on future studies since it provides detailed information about the current status of the literature in topology-based routing approaches in VANETs.**

Index Terms—**Proactive, reactive, survey, topology, vehicular ad hoc networks routing.**

I. Introduction

VEHICULAR AD HOC NETWORKS (VANETS), an increasingly important component of Intelligent Transport Systems (ITS), consist of vehicles in motion communicating with each other and road side units (RSU) as infrastructures. VANET, as seen in Fig 1, is a popular topic in both academia and industry due to its usage in critical areas such as enhancing traffic safety and efficiency, providing real-time and secure data to drivers and passengers, and managing emergencies such as accident prevention, ambulance guidance and fire brigade assistance [1].

VANET services can be summarized as follows [2]:

• Security service: Providing automatic driving functions and mitigating traffic risks,

• Data sharing services: Enhancing communication comfort for drivers and passengers by exchanging information about the surrounding road conditions.

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In order to provide these services, VANETs need to process real-time data on the network. These networks exhibit a dynamic topology due to the high mobility of vehicles. As vehicles frequently change their positions within the network, interruptions in established routes occur frequently [3]. Therefore, setting up the route from source to destination is a difficult task in VANETs [4]. Routing protocols play a crucial role in reducing network congestion by enabling dynamic routes between vehicles. The reduction in network traffic can yield economic benefits such as reduced battery and fuel consumption in vehicles. Numerous studies in the literature are dedicated to develop a routing protocols specifically designed for VANETs [1],[2],[4].

Routing protocols in VANETs are categorized into different classes, including topology-based, position-based, broadcast-based, cluster-based, and geo-cast-based approaches [5]. Among these, topology-based routing focuses on determining the optimal route between the vehicles by utilizing and analyzing information such as the current road and traffic conditions. This approach enhances the security of data flow while reducing both packet losses and delays [6]. Consequently, topology-based routing architectures have garnered significant attention from researchers due to their pivotal role in improving the efficiency, security and performance of VANETs.

While there are existing review articles for position-based [7]-[12][7] below, broadcast-based [13],[14], cluster-based [15],[16] and geo-cast-based [17],[18] routing architectures in VANETs, the number of surveys analyzing recent topology-based protocols [19],[20] is relatively limited. Therefore the objective of this study is to classify topology-based VANET routing protocols and conduct a detailed examination of each class. The studies are compared using tables on various parameters, and open research areas are highlighted. It is anticipated that this paper will provide valuable insights into future developments of topology-based routing algorithms in VANETs.

Section II of the paper provides a review of the existing studies in the literature and highlights the contribution of this study. Section III presents a summary of the research methodology employed in this study. In Section IV, a comprehensive analysis of the examined topology-based studies is provided, clarifying the details of each study. Section V involves the general comments and remarks obtained from the reviewed studies. Finally, Section VI concludes the paper.

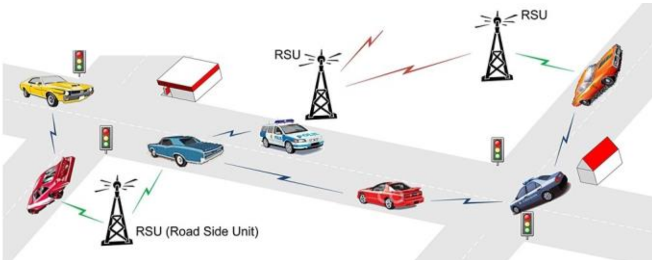

Fig.1. A VANET infrastructure consisting of vehicles and RSUs

II. LITERATURE REVIEW

In the literature, various classification types of routing algorithms and protocols in VANETs can be found. For instance, Srivastava et. al [[7]], classify the routing protocols into two classes based on transmission strategy and route formation. The transmission strategy class includes unicast, multicast (such as geo-cast and cluster-based approaches), and broadcast approaches. The route information class can be further divided into location-based and topology-based approaches. Other studies [[5], [13], [20]] categorize routing protocols in VANETs into five classes including position/geographic/location-based, cluster-based, broadcast-based, geo-cast based and topology-based protocols. In this study, five different class of routing architectures are considered as illustrated in Fig. 2.

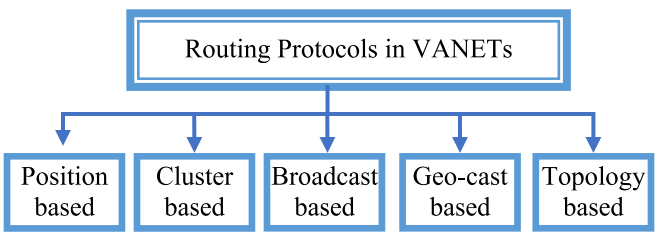

Fig.2. Classification of routing protocols in VANETs

In position based routing, the focus is on utilizing the geographic location information of the nodes rather than establishing end-to-end connectivity [[7]]. Cluster-based routing approaches divide the network into smaller regions known as clusters [[16]]. A designated node, known as the cluster head, is responsible for collecting and transmitting data from its member nodes within the cluster. In broadcast-based routing protocols [[13]], data packets are propagated throughout the network using broadcast transmission techniques. Geo-cast routing [[17]], a type of position-based routing, selects a specific area based on the location of the destination vehicle and transmits data through broadcasting within that relevant area. Topology-based routing protocols [[20]] operate by utilizing the network's connectivity information to create routing tables. These protocols are further classified into three classes: proactive, reactive and hybrid. Topology-based routing protocols offer advantages such as being suitable for smaller networks and endeavoring to find the optimal (i.e., shortest) route from the source to the destination node [[21]].

Most of the recent survey papers (published between 2017 and 2023) focusing on routing protocols in VANETs primarily concentrate on position-based approaches [[7]-[12]]. Some studies delve into broadcast-based [[13],[14]], cluster-based [15],[16], and geo-cast-based [17],[18] methods. Additionally, there are reviews [14],[22],[23] that examine protocols from the perspective of quality of service (QoS). However, survey papers specifically addressing topology-based routing are relatively scarce. One study is tailored for FANETs [19], while another [20] examines only four different protocols, comparing their performances through simulation under various metrics. Thus, it is evident that there is a need in the literature for a review article that sheds light on recent papers focusing on topology-based routing approaches.

The objective of this study is to provide an overview of the state-of-the-art in recent topology-based routing architectures in the literature. The contributions of this study can be summarized as follows:

- Examination of 38 different topology-based routing approaches: The study conducts a comprehensive analysis of 38 distinct approaches, providing detailed insights into each approach.
- Classification and comparison: The papers are categorized based on their routing architectures, and a comparative analysis is performed within each class. The approaches are evaluated and compared with respect to various routing and network parameters. The advantages and disadvantages of each approach are emphasized.
- Identification of open research areas: The study identifies and highlights open research areas that assure further investigation and exploration in the field of topology-based routing in VANETs.

III. RESEARCH METHODOLOGY

By synergistically combining cutting-edge research, real-world experience, and deeply ingrained human values, Evidence-based Software Engineering (EBSE) endeavors to elevate decision-making practices in software development and maintenance to new heights [24]. The foundation of EBSE relies heavily on the utilization of systematic reviews. A systematic literature review (SLR) is a rigorous and exhaustive evaluation of all available research pertaining to a particular research question, topic area, or phenomenon of interest [24], [25]. The primary objective of conducting an SLR is to ensure a methodical, replicable, and thorough review process. By employing systematic reviews, EBSE ensures a robust and unbiased approach to synthesizing evidence for informed decision-making in software development and maintenance [26]. Therefore, we have followed one of the widely recognized systematic review guidelines [26] and we have applied the same strategy as in the existing literature, e.g., [27][28], [29].

The papers included in this study were collected from four databases: IEEE Xplore, ScienceDirect, Springer, and Google Scholar. Both conference and journal publications were considered in the search.

Based on the information provided in [30], which states that protocols like AODV, DSR, DSDV, and OLSR proposed for MANETs form the foundation of topology-based routing protocols in VANETs, the searches were divided into two groups:

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1. The keywords "PROACTIVE OR REACTIVE OR TOPOLOGY AND ROUTING AND VANET" were used to find both hybrid protocols and topology-based approaches.
2. The keywords "AODV or DSR or DSDV or OLSR and VANET" were used to identify different versions or variants of these foundational protocols.

After obtaining 724 articles, those that solely compared the performance of existing protocols, that do not have full text, that are not written in English, that do not verify the proposed methodology and review/survey papers were excluded. Duplicate studies were also eliminated. Thus, the number of articles was reduced to 28. The original versions of the relevant studies were identified manually and included by thoroughly examining the articles. As a result, a total of 38 articles were obtained.

By conducting this search strategy, the study aims to gather a comprehensive collection of relevant articles on topology-based routing protocols in VANETs, ensuring the inclusion of original research and minimizing redundancy.

IV. Overview of Topology-based Routing

Topology-based routing protocols in VANETs employ routing tables on nodes to handle data transmission and update these tables as the network topology changes. Message transmission can be performed using three methods: unicast, multicast and broadcast. These protocols are classified into three classes: proactive, reactive and hybrid as depicted in Fig 3 [30]

Proactive routing protocols, also known as table-driven routing, manage and store routing information about all nodes in the network in tables located at every node. Nodes ensure that the routing information is kept up-to-date by exchanging tables with other nodes to accommodate changes in the network topology [19], [24].

In reactive routing protocols, also known as on-demand routing, the route to the destination node is discovered when a node wants to forward a data packet to another node. However, unlike proactive routing protocols, the routing table is not continuously updated. Instead, only active routes are logged and maintained [19], [24].

In this paper, proactive, reactive, and hybrid approaches are individually investigated and analyzed. Each approach is briefly summarized, highlighting its key characteristics. To provide a comprehensive understanding and facilitate comparison, tables are created to compare the updating strategies employed by these approaches. These tables allow for a systematic evaluation of the pros and cons of each approach, shedding light on their respective strengths and weaknesses. By presenting this comparative analysis, the paper aims to provide valuable insights into the different updating strategies and their implications in VANET routing protocols.

A. Proactive Solutions

Proactive routing protocols in VANETs can be classified into two main classes: Distance Vector Algorithm [31] and Link State Algorithm [32], based on their routing approaches. Distance Vector-based protocols utilize the Bellman-Ford Algorithm [33] for routing decision-making. On the other hand, Link State-based protocols employ the Dijkstra Algorithm [34] for route computation.

Distance vector based proactive routing protocols are summarized as below and the comparison of these protocols with their advantages and disadvantages are shown in Table I.

In Distance Vector Routing Protocol (DVRP), each node maintains a routing table that stores information about its distance to other nodes in the network and the optimal route to reach those nodes. The routing table is periodically exchanged with neighboring nodes or in the event of a network disconnection. This process continues iteratively until each node in the network has updated its routing table with the most optimal paths to all destinations [35].

In Destination-Sequenced Distance Vector Routing (DSDV), each node in the network determines the optimal path to destinations based on the distance vectors provided by its neighboring nodes. However, DSDV introduces the use of sequence numbers to prevent routing loops and ensure consistent routing table formation. Another key feature of DSDV is the partial update of routing tables. Instead of updating the entire routing table, DSDV only updates entries for the destination networks that have experienced changes. This approach reduces the overhead on network traffic, as nodes transmit and process only the necessary updates, rather than exchanging complete routing tables [36].

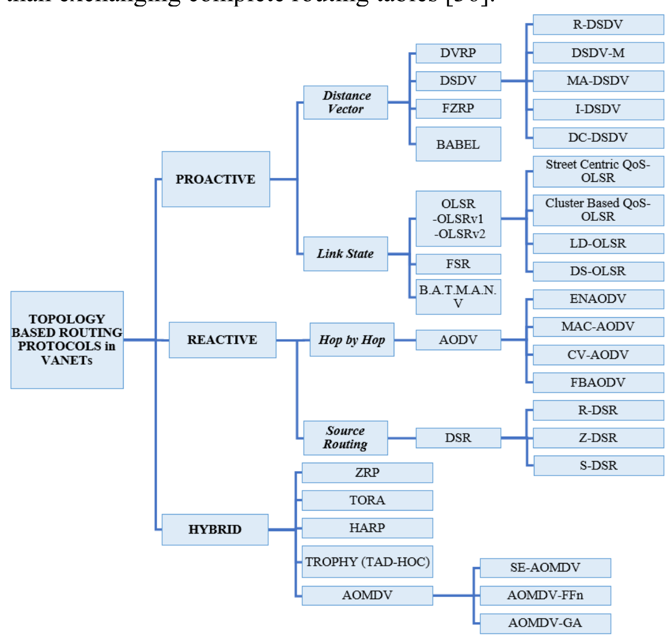

Fig.3. Topology-based routing protocols in VANETs

In Randomized-DSDV (R-DSDV), routing tables are updated at random time intervals to distribute network traffic and facilitate the rapid dissemination of updated routing information [37].

In Multi-Agent-DSDV (MA-DSDV), individual agents maintain their own routing tables and exchange routing information with neighboring agents to ensure up-to-date table information. This approach enables effective and efficient routing in complex network environments [38].

Dual-Interface Multiple Channels (DSDV-M) is a routing protocol designed for networks with devices having multiple wireless interfaces. It allows nodes to maintain updated routing tables, enabling effective communication across multiple wireless channels simultaneously. This enhances network capacity and flexibility [39].

Improved-DSDV aims to enhance the stability of routing information in the network by responding more quickly to topology changes compared to the classical DSDV protocol. It achieves this by minimizing routing information changes between nodes, thereby reducing energy consumption. Timestamps are used in shared routing tables to mitigate routing errors and ensure reliable sharing of routing information. The protocol focuses on improving the overall reliability and efficiency of routing in the network [40].

region have more frequent updates in their routing tables, while nodes farther away have less frequent updates [42].

BABEL is a versatile routing protocol that enables the use of multiple paths with different metrics. It dynamically updates routing tables to optimize path selection based on factors such as link quality, available bandwidth, and delay. This enhances network reliability and adaptability [43]-[45].

Link state-based proactive routing protocols are summarized as below and the comparison of these protocols with their advantages and disadvantages are shown in Table II.

OLSR is used for determining the shortest path and routing network traffic by establishing the connection states between the nodes. This protocol follows the neighborhood relations and link states of the nodes; shares them among the nodes and creates the routing table accordingly [46]-[48].

Street Centric QoS-OLSR is an extension to the OLSR protocol, which provides QoS support. This protocol optimizes communication in the network by considering physical routes such as streets and avenues and performs routing accordingly. By leveraging street-centric information, Street Centric QoS-OLSR selects routes that take into account the specific characteristics and constraints of the physical environment [49].

Cluster Based QoS-OLSR is also an extended version of the OLSR protocol that incorporates QoS support. This protocol introduces a logical division of the network into clusters, where each cluster is assigned a cluster head. By centralizing the routing decisions within each cluster, the protocol enables better management of QoS requirements in the network [50].

An QoS Aware Link Defined-OLSR (LD-OLSR) is an extension of the OLSR protocol that incorporates QoS support. This protocol is designed to route traffic with different levels of service qualities in the network, ensuring that priority traffic, such as voice or video data, is given lower latency and reduced packet loss rates. By reducing the disparity between different levels of QoS, LD-OLSR aims to provide a more consistent and reliable service in the network [51].

Disaster Scenario Optimized-OLSR (DS-OLSR) is also an extended version of OLSR protocol specifically designed to address the challenges of communication network configuration in disaster scenarios. Since this protocol can replace disconnected nodes with other nodes after a natural disaster, it ensures the essential communication functionality required for emergency activities [52].

Divide Cluster-DSDV divides the network into smaller subnets, managed by dedicated routing nodes. Subnets share local routing information, reducing network traffic and enabling faster routing decisions. Bridge nodes facilitate communication between subnets when needed, improving overall network efficiency and scalability [41].

Fisheye Zone Routing Protocol (FZRP) is a routing protocol designed to control network traffic by limiting updating of routing tables between nodes. Each node in the network updates the routing information of its neighbors and maintains up-to-date routing tables based on this information. However, the frequency of updating the routing tables of neighboring nodes is dependent on their distance. Nodes in a specific

FSR performs the routing process by focusing on a specific zone within the network nodes. The protocol maintains two distinct routing tables, including global and local, to route the communication between the nodes. The global routing table contains general information about all nodes in the network including their connections. On the other hand, the local routing table includes detailed information about the connections between the nodes and their neighbors [53].

Better Approach to Mobile Ad-Hoc V (B.A.T.M.A.N V) constantly monitors the link quality between nodes in the network and makes the routing decisions by selecting the most reliable links. This approach aims to improve network efficiency and reliability [54]-[55].

B. Reactive Solutions

Reactive protocols allow the nodes in the network to communicate directly with each other. Basically, these protocols are divided into two classes according to routing logic, including node-to-node hop (Hop by Hop[56]) and source routing (Source Routing[57])[62]. In hop by hop routing, the data transmitted from one node to another is received and directed by each node. This way, data is routed by each node until it reaches the destination node. This technique is used to choose the shortest path [56]. On the other hand, data is directly routed to the destination node by the sending node in source routing. In this method, the sending node determines relay nodes through which the data must pass to reach the destination node, and relay information is sent along with the data. This routing technique can provide the best route selection when there are obstacles or constraints in the network [57].

Hop by Hop reactive routing protocols are summarized as below and the comparison of these protocols with their advantages and disadvantages are shown in Table III.

Ad-hoc On-demand Distance Vector (AODV) calls for only the necessary nodes to establish a direct route when a data packet needs to be routed from a source node to a destination node. Therefore, it effectively utilizes the resources of the nodes in the network and increases network efficiency [56].

Enhanced AODV (ENAODV) is an enhanced version of the AODV protocol, designed to achieve high performance, low latency and high efficiency. To achieve these objectives, ENAODV considers the distance between nodes and constructs the shortest path [58].

Medium Access Control-AODV (MAC-AODV) is a combination of protocols designed for both the MAC layer and the routing layer. It is used to control data transmission and routing between the nodes in the network. MAC-AODV aims for low latency and high efficiency, making it particularly popular in low power consumption devices such as smart devices and smart sensors [59].

Compatibility Based Vehicular Ad-Hoc Networks-AODV (CV-AODV) is particularly used in autonomous vehicles, intelligent transportation systems and traffic routing applications. It is known for providing high efficiency, rapid data transmission and secure data communication [60].

Fitness Based AODV (FBAODV) is a protocol that constructs routes based on the physical states of the nodes in the network. It is designed to select the most suitable routing paths by considering the location, speed, energy level and physical state of the nodes [61].

Source routing reactive routing protocols are summarized as below and the comparison of these protocols with their advantages and disadvantages are shown in Table IV.

TABLE I
THE COMPARISON OF DISTANCE VECTOR BASED PROACTIVE ROUTING PROTOCOLS

Protocol	Network Size	Routing Table Updating Strategy and/or Frequency	Advantages	Disadvantages
DVRP[35]	Medium-Large	• updating when an event occurs (when a new node is discovered or lost) • updating with periodic time intervals	• high reliability • low latency	• high update traffic • high memory usage
DSDV[36]	Small-Medium	• updating when an event occurs (when a new node is discovered or lost) • updating with periodic time intervals	• low complexity • simple structure	• high update traffic • low mobility support
Randomized DSDV[37]	Small-Medium	• updating with random time intervals	• low update traffic • low complexity	• random update interval • low mobility support
Multi-Agent DSDV[38]	Medium-Large	• using multiple agents • updating when there is a change in the routing tables of the nodes • updating with periodic time intervals	• high scalability • local update	• agent coordination requirement • complex structure
DSDV- Dual Interface Multiple Channels[39]	Small-Medium	• using dual interface and multi-channel • updating when there is a change in the routing tables of the nodes • using active and passive routing tables	• channel variety • low latency	• high hardware requirement • complex structure
Improved-DSDV[40]	Medium-Large	• updating a limiting number of nodes • updating when there is a change in the routing tables of the nodes • updating with periodic time intervals	• low update traffic • low complexity	• additional communication cost
Divide Cluster DSDV[41]	Medium-Large	• dividing network into clusters • updating with periodic time intervals for the leader nodes • updating when there is a change in the routing tables of the other nodes	• scalability • local update	• management problems and difficulties in subnets
Fisheye Zone Routing Protocol[42]	Medium-Large	• updating remote zones using the "Fisheye" routing table • updating when there is a change in the routing tables of the nodes in the relevant domain • updating with periodic time intervals for all nodes	• low update traffic • rapid update of topology information	• high memory usage • routing complexity • high latency
BABEL[43][44][45]	Medium-Large	• updating based on the link states of the nodes • updating when there is a change in the routing tables of the neighbouring nodes • updating with periodic time intervals for all nodes • updating all affected nodes when a node in the network is disconnected from its neighbour	• high scalability • low memory usage	• complex routing policies • high update traffic

TABLE II
THE COMPARISON OF LINK STATE BASED PROACTIVE ROUTING PROTOCOLS

Protocol	Network Size	Routing Table Updating Strategy and/or Frequency	Advantages	Disadvantages
OLSR[46][47][48]	Small-Medium	• periodic topology control messages • allowing nodes to recognize each other and notify topology changes	• high efficiency • low latency	• complex structure
Street Centric QoS-OLSR[49]	Small-Medium	• periodic topology control messages • considering QoS requirements	• street centric QoS Support	• complex structure
Cluster Based QoS-OLSR[50]	Medium-Large	• periodic topology control messages • considering QoS requirements • primarily updating by choosing the nodes within cluster	• high scalability • low network traffic	• complex structure
LD-OLSR[51]	Small-Medium	• periodic topology control messages • considering QoS requirements • using high-speed connection if available	• routing with QoS information	• complex structure
DS-OLSR [52]	Small-Medium-Large	• periodic topology control messages • using emergency signal in case of disaster • considering the integrity of the network, energy efficiency and communication quality	• high durability • high scalability	• low efficiency • high latency

FSR[53]	Small-Medium	• dynamic update when the link states change • Frequent updating for closer nodes, infrequent updating for distant nodes	• low routing table size • low network traffic	• high latency • low routing table update frequency
B.A.T.M.A.N V [54][55]	Small-Medium	• dynamic update when needing to find a new route • monitoring the link state of neighbours	• low configuration requirement • low latency	• high routing table size

TABLE III
THE COMPARISON OF HOP BY HOP REACTIVE ROUTING PROTOCOLS

Protocol	Network Size	Routing Table Updating Strategy and/or Frequency	Advantages	Disadvantages
AODV[56]	Large	• updating depends on the distance between the nodes and the energy level of the nodes • on-demand approach	• fast forwarding • efficient updating	• performance can be poor at high node density
ENAODV[58]	Large	• updating depends on the distance between the nodes • on-demand approach	• efficient updating • high network performance	• complex structure • requires much computation
MAC-AODV[59]	Small	• minimizing routing table • on-demand approach. • time-basis updating	• low energy consumption • low delay	• low scalability • low flexibility
CV-AODV[60]	Large	• updating depends on the availability between the nodes • on-demand approach	• effective routing • high network performance	• low scalability • low flexibility
FBAODV[61]	Small	• using genetic algorithm and simulated annealing for updating • on-demand approach	• low energy consumption • low delay	• low scalability • low flexibility

Reliable DSR (R-DSR) is a derivative of DSR protocol that aims to mitigate packet loss in wireless ad hoc networks. R-DSR operates similarly to DSR by utilizing routing packets containing route information. However, unlike DSR, the RDSR protocol incorporates a reliability mechanism that allows for retransmission the lost packet in event of packet losses [63].

Zone Based DSR (Z-DSR) updates the routing table by utilizing the concept of "zones" that are created based on the geographical locations of nodes in the network. The ZDSR protocol considers distances and geographic locations between nodes to gain a better understanding of the network topology. This approach reduces the number of required routing packets between nodes, resulting in reduced network traffic. Consequently, the performance of the network increases as congestion decreases [64].

Segment Based DSR (S-DSR) proposes a similar approach to the DSR protocol. However, S-DSR enhances data integrity by dividing data into segments rather instead of packaging it as a whole. This approach reduces the risk of data loss within the network and ensures higher data reliability [64].

C. Hybrid Solutions

Hybrid protocols are designed to minimize control overhead in proactive solutions and reduce the delay in searching for an initial path in reactive approaches [65]. The objective of hybrid routing protocols is to efficiently manage data traffic by combining several proactive and reactive routing algorithms and leveraging the strengths of both approaches [66]. Table V provides a comparison of these protocols, including their advantages and disadvantages.

Zone Routing Protocol (ZRP) divides the network into zones, where each node within a zone is informed about its neighbors using proactive routing. However, when it comes to routing data to remote nodes, zones employ reactive routing. ZRP utilizes the redundant path feature, allowing for the utilization of multiple paths in the network. However, these redundant paths can lead to increased network traffic, resulting in high latency [67].

Temporally-Ordered Routing Algorithm (TORA) creates a hierarchical routing tree from the nodes in the network using proactive routing. Reactive routing is employed for delivering the data to destination node. TORA is known for its effectiveness in reducing latency and improving network performance. However, as the number of nodes increases, updating the tables in TORA requires high bandwidth usage [68].

Hybrid Ad Hoc Routing Protocol (HARP) aims to enhance the performance of the network by combining proactive and reactive routing approaches. HARP maintains a proactive routing table where information about the overall topology of the network is stored. Reactive routing is employed for data transmission to destination node. While HARP boasts low energy consumption, the routing tables of all nodes need to be updated as the network topology changes [69].

TAD-Hoc/TROPHY is a routing protocol that leverages the location information of the nodes to determine the optimal routing path. By considering the battery states of the nodes, TROPHY aims to achieve energy efficiency and low power consumption The protocol utilizes reactive routing features to update the routing tables, with updates occurring only when the destination node is first accessed [70].

An Optimized Ad-Hoc On-Demand Multipath Distance Vector (AOMDV) is a hybrid protocol that combines the features of AODV and DSDV protocols. AOMDV uses an on-demand routing strategy along with the capability to establish multiple paths. This enables faster and more reliable transmission of data packets to destination nodes. AOMDV has been used as a foundation in various studies within the literature [71].

Secure and Efficient-AOMDV (SE-AOMDV) is a protocol specifically designed to enhance both the security and efficiency of the AOMDV protocol. It retains the hybrid structure of AOMDV while introducing additional features to ensure secure data transmission. These features include secure route selection, data packet encryption, authentication, and message integrity mechanisms. While these enhancements improve the security of the protocol, they also come with the drawback of increased processing and storage costs due to the additional computational and storage requirements associated with the security mechanisms [72].

AOMDV- Fitness Function (FFn) introduces a fitness function to AOMDV protocol. The fitness function is designed to ensure communication security, to reduce energy consumption and to prevent packet losses by using node specific characteristics, including battery level and hop count. AOMDV-FFn employs a selective interfacing method to improve communication quality. However, AOMDV-FFn requires high processor power and memory usage [73].

AOMDV- Genetic Algorithm (GA) incorporates a genetic algorithm to elect the best route. The goal of this protocol is to minimize energy consumption, prevent packet losses and increase data transmission speed. However, utilization of a genetic algorithm comes at the cost of high processing power and memory usage [73].

TABLE IV
THE COMPARISON OF SOURCE REACTIVE ROUTING PROTOCOLS

Protocol	Network Size	Routing Table Updating Strategy and/or Frequency	Advantages	Disadvantages
DSR[57]	Small-Medium	• dynamic update for every packet	• low packet delay • high routing performance	• high network traffic • high network delay
R-DSR[63]	Medium	• dynamic update for every packet • using both regular and quick updating	• high reliability • low packet loss	• high network traffic • low flexibility
Z-DSR[64]	Large	• periodic update • using geographic regions and zone tables • using active and passive routing	• high forwarding performance • low network traffic	• complex structure • difficulty in determining node boundaries
S-DSR[64]	Large	• dynamic update for every packet • using segment table • using active and passive routing	• high routing performance • low network traffic	• complex structure • high computing power

TABLE V
THE COMPARISON OF HYBRID ROUTING PROTOCOLS

Protocol	Network Size	Routing Table Updating Strategy and/or Frequency	Advantages	Disadvantages
ZRP[67]	Medium-Large	• regular updating • using both proactive and reactive routing approaches	• several path usage	• high network traffic • high network delay
TORA[68]	Small-Medium	• regular updating • using proactive approach	• high network performance • low delay	• high bandwidth usage • high computation cost
HARP[69]	Medium-Large	• regular updating • using both proactive and reactive routing approaches	• low energy consumption	• reforming when topology changes
TROPHY(TAD-Hoc)[70]	Medium-Large	• updating when first access • using reactive approach	• Low bandwidth usage • low delay	• low scalability • low flexibility
AOMDV[71]	Medium-Large	• regular updating • using both proactive and reactive routing approaches	• low energy consumption • low delay • high reliability	• reforming when topology changes
SE-AOMDV[72]	Medium-Large	• updating when first access • using reactive approach	• high communication quality	• high processing power • high memory usage
AOMDV-FFn[73]	Medium-Large	• regular updating • using both proactive and reactive routing approaches	• high network performance	• high processing power • high memory usage
AOMDV-GA[73]	Medium-Large	• updating when first access • using reactive approach	• low energy consumption • low delay • low packet loss	• high processing power • high memory usage

V. Discussion

In the previous section, we conducted a detailed evaluation of individual protocols within each group. In this section, we will provide general evaluations for each group of protocols. Then we will emphasize open research areas.

When evaluating distance vector based proactive routing protocols, it is evident that these protocols can effectively scaled to network of various sizes, ranging from small to large. The update strategy of the routing tables in these protocols is typically based on event-driven updates (such as the discovery or loss of a node) or periodic updates that occur independently of any specific event. While these protocols ensure that the routing tables remain up-to-date, they do have certain drawbacks, including high memory usage and increased traffic for updating the tables.

The link state approach is commonly used in smaller and medium-sized networks, although the DS-OLSR protocol can be scaled to networks of any size. Protocols such as OLSR and modified OSLR update their routing tables periodically, while protocols like FSR and B.A.T.M.A.N-V dynamically update their tables whenever there are changes in link status or route discovery. One advantage of link state proactive routing protocols is that scalability and QoS support can be added as additional features. However, these protocols also have some drawbacks, including complex configuration difficulties, high latency, and large routing tables. As a result, they are generally not preferred for large-scale networks.

Hop-by-hop based reactive protocols are suitable for networks of any size. In this group, routing tables are updated as needed, resulting in efficient routing table updates and low energy consumption. As a result, these protocols can be preferred in large-scale networks. However, configuring the network and addressing scalability issues, especially in modified versions like increasing reliability in the ADOV protocol, can pose challenges that need to be addressed.

Source-based reactive protocols can be utilized in networks of any size, although they particularly suitable for large networks. Update tables are dynamically performed each time a packet is transmitted. The limitations of these protocols are that they can cause high processing power and high network traffic.

Hybrid protocols offer the flexibility to create application-specific solutions for networks of any size since they utilize both proactive and reactive approaches. Some protocols update their routing tables periodically, while others update them only upon the first transmission of a data packet. Additionally, there are approaches that employ both regular and on-demand updating. While the combination of proactive and reactive routing approaches brings about several advantages, it is crucial to address the issues of high processing power and memory usage associated with these protocols.

The evaluations have indicated that the following areas present opportunities for further research.

1. QoS support: Irrespective of the protocol type, it is essential to provide QoS support that caters to the specific requirements of the application, as well as ensuring independent QoS provision.

2. Scalability: The scalability of protocols poses challenges in large networks, as those designed for efficient operation in small networks often encounter issues such as memory shortage and increased network load. To address this, it is crucial to focus on resolving reliability and efficiency issues to prevent system degradation and ensure optimal performance in larger network environments.

3. Data losses: Efforts should be made to tackle the issue of routing table loss in nodes caused by frequent disconnections due to high mobility, especially in scenarios where long-term data storage is not available. Finding solutions to mitigate this problem is crucial to maintain efficient and reliable routing in such dynamic environments.

In order to mitigate the potential threat to the validity of our study, we have implemented proactive measures in relation to the selection of digital libraries and search terms. To overcome this concern, we utilized four esteemed digital libraries in the field of computer science. These libraries offered a wealth of resources and diverse search query structures, enabling us to establish precise search terms. By incorporating these robust digital libraries, our intention was to enhance the accuracy and comprehensiveness of our research while minimizing biases associated with the selection of libraries or formulation of search terms.

VI. Conclusion

VANET, a network designed for wireless communication between vehicles, is utilized for various purposes such as enhancing traffic safety, managing emergencies and increasing passenger comfort through communication between vehicles and vehicle-roadside units.

In this study, we have conducted a comparative analysis of topology-based routing protocols in VANETs. These protocols utilize the vehicle locations to automatically determine the network topology and ensure efficient data transmission through the shortest path. As a result, topology-based protocols play a crucial role in achieving reliable and efficient routing in VANETs.

We classified the topology-based routing protocols in VANETs and arranged them in chronological order from basic to the most up-to-date, considering their acceptance by academic communities. Comparative feature tables were created to showcase their usage characteristics. Detailed analyses and comments were conducted for both individual protocols and the overall class.

The following results can be obtained from a general perspective for topology-based routing approaches:

- Distance vector based proactive routing approaches provides up-to-date routing tables but suffer from high memory usage and high data traffic for updating the tables.
- Link-state based proactive approaches can support QoS. However, they have drawbacks of complex network configuration difficulties, high latency, and large size of routing tables.
- Although hop by hop reactive protocols, offer efficient routing table updating and low energy consumption, they have difficulty in configuring the network and scalability issues.
- Source routing based reactive approaches have the ability to address any network size. However, they can cause high processing power and high network traffic.
- Although hybrid approaches combine the beneficial aspects of proactive and reactive protocols, they may require additional processing power and memory usage to handle the integration of both approaches effectively.

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