World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Review Article)

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Routing Protocols for Vehicle-to-Vehicle (V2V) Networks

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World Journal of Advanced Research and Reviews, 2023, 19(01), 334–339

Publication history: Received on 25 May 2023; revised on 04 July 2023; accepted on 06 July 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.19.1.1321

Abstract

VANET, short for Vehicle Ad-hoc Network, is an emerging technology with unique characteristics that differentiate it from previous ad-hoc networks. Designing an effective routing protocol for V2V (vehicle-to-vehicle) communication and V2I (vehicle-to-roadside infrastructure) communication is particularly challenging due to the dynamic nature of topology and frequent disconnections. VANET plays a crucial role in the development of Intelligent Transportation Systems (ITS) aimed at enhancing traffic flow and safety, primarily due to the high occurrence of traffic accidents. However, existing VANET routing protocols face limitations in effectively handling diverse traffic scenarios. To ensure future communication between vehicles for road safety, it is essential to develop appropriate routing protocols. This paper focuses on analyzing the advantages and disadvantages of routing protocols that can contribute to the development of new or improved routing protocols in the near future.

Keywords: VANET; V2V; V2I; Routing Protocols; Road Safety

1. Introduction

Vehicular Ad-hoc Network (VANET) has gained significant academic interest in recent years. Research initiatives such as COMCAR, DRIVE, FleetNet, NoW (Network on Wheels), CarTALK 2000, and CarNet are being conducted worldwide to explore this technology. VANET is a self-organizing wireless communication network where vehicles, acting as nodes, serve as servers, clients, or both, facilitating the exchange of information. Figure 1 illustrates various applications planned for VANET, some of which are already implemented in modern vehicles.

VANET enables vehicles to communicate with each other, offering numerous benefits such as preventing roadside accidents, mitigating traffic congestion, facilitating speed control, ensuring the smooth flow of emergency vehicles, and detecting invisible obstructions. However, developing applications for VANET can be challenging due to its unique characteristics that differentiate it from Mobile Ad-hoc Networks (MANETs).

Several studies have focused on analyzing the performance of VANET routing protocols. However, building new routing protocols for VANET is exceptionally difficult due to the significant variations in vehicle movement patterns compared to traditional ad hoc network systems. In this research article, we aim to explore the advantages and disadvantages of VANET routing protocols. The structure of the remaining sections is as follows: Sections II and III, IV, V, VI, and VII delve into the benefits and drawbacks of Topology-Based Routing Protocols, Position-Based Routing Protocols, Cluster-Based Protocols, Broadcast Protocols, and GeoCast Protocols, respectively. Section II provides an overview of VANET routing protocols, while in Section VIII, we conclude our findings and provide references.

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2. Topology-Based Routing Protocol

Topology-based routing techniques use network link information to transport data packets from source to destination. Proactive (table-driven) and reactive (on-demand) routing strategies are subcategories of topology-based routing.

2.1. Proactive (table-driven) Protocol for Topology-Based Routing

Proactive routing methods rely on shortest path computations and utilize table-based protocols to store node data. This ensures consistent information among neighbor nodes, eliminating the need for route discovery procedures and making them suitable for low-latency real-time applications. Nevertheless, a drawback of proactive routing is suboptimal bandwidth utilization due to the allocation of unused paths.

2.1.1. Fisheye State Routing

Fisheye State Routing (FSR) is a proactive routing algorithm that exchanges information among nearby nodes to compute routing tables. It efficiently utilizes bandwidth by sharing only partial routing update information with neighbors. Nonetheless, FSR exhibits decreased network efficiency in ad hoc networks and may have limited knowledge of remote nodes, leading to potential routing inefficiencies. Additionally, managing and maintaining the routing infrastructure becomes more complex as the network size increases.

2.2. Reactive (On Request)

Reactive routing, also known as on-demand routing, optimizes network bandwidth by initiating route discovery only when necessary. It minimizes unnecessary network traffic but may introduce latency during the route finding process. Excessive network flooding can hinder effective communication and impede network efficiency.

2.2.1. Ad Hoc on Demand Distance Vector (AODV)

Ad Hoc on Demand Distance Vector (AODV) is a reactive routing approach that utilizes a destination sequence number for enhanced functionality. It offers both multicast and unicast routing capabilities, ensuring current routes to the destination, reducing memory usage, and eliminating route redundancy. AODV promptly reacts to network link loss, making it suitable for sizable ad hoc networks. Nevertheless, it may have increased communication and connection setup time, potential routing inconsistencies, and significant control overhead from multiple route reply packets.

2.2.2. Dynamic Source Routing

Dynamic Source Routing (DSR) protocol utilizes source routing and employs active route maintenance and route discovery mechanisms. It operates without periodic updates and reduces network demand through caching. Nonetheless, the presence of route information in the header can result in byte overhead, and excessive flooding can strain the network. DSR exhibits poorer performance in scenarios with significant node movement and lacks the ability to locally repair damaged links, potentially affecting network connectivity.

2.2.3. Temporally Ordered Routing Protocol (TORA)

The Temporally Ordered Routing Protocol (TORA) is a link reversal-based routing protocol that establishes a directed acyclic network. TORA designates the source node as the root and uses directed links towards the destination. When a node sends a packet, it broadcasts it, and neighboring nodes rebroadcast based on the directed acyclic graph (DAG) structure. TORA offers benefits such as generating a DAG when needed, reducing network overhead by avoiding message rebroadcasting. It performs well in dense networks. However, TORA is not widely used in practice, as Dynamic Source Routing (DSR) and Ad Hoc On-Demand Distance Vector (AODV) outperform TORA in terms of scalability and overall performance.

3. Position-Based Routing Protocol

Position-Based Routing (PBR) protocols use position information, like GPS, to determine node locations and find routes. PBR does not rely on routing tables or link state information. Instead, it utilizes node positions for routing decisions. Examples of position-based greedy V2V protocols include GSR, GPSR, GPCR, CAR, A-STAR, and STBR. PBR offers advantages such as efficiency, scalability, and suitability for highly mobile environments. Nonetheless, PBR requires position determination assistance, often from GPS or similar technologies, and may face challenges in signal-obstructed environments like tunnels.

3.1. Greedy Perimeter Stateless Routing (GPSR)

Greedy Perimeter Stateless Routing (GPSR) is a position-based routing protocol that selects the closest node to the destination using a beacon. It employs greedy forwarding and switches to perimeter forwarding if the initial greedy forwarding fails. GPSR has advantages such as reduced memory requirements and dynamic packet forwarding decisions. Nevertheless, it may encounter issues with stale neighbor position information and potential routing problems due to outdated packet headers.

3.2. Greedy Perimeter Coordinator Routing (GPCR)

Greedy Perimeter Coordinator Routing (GPCR) is a position-based routing protocol designed for city scenarios. It utilizes greedy algorithms to forward packets along a predetermined path, independent of global or external information. GPCR overcomes planarization problems and uses road structures to represent the planar graph. However, it relies on junction nodes, which introduce complexities, and may face difficulties on curved or sparse roads.

3.3. Connectivity-Aware Routing (CAR)

Connectivity-Aware Routing (CAR) is a routing protocol for city and highway environments. It combines the Ad Hoc On-Demand Distance Vector (AODV) protocol for path discovery with PGB (Propagation of Geographical Broadcasting) for data dissemination. CAR incorporates the guard concept to maintain the established path and ensures finding the shortest connected path. CAR offers advantages such as avoiding local maximum issues and achieving higher packet delivery ratios. Nonetheless, it may select unnecessary anchors and face challenges in adapting to changing traffic environments.

3.4. Geographic Source Routing (GSR)

Geographic Source Routing (GSR) combines position-based routing with topological knowledge. It utilizes greedy forwarding along a preselected shortest path calculated using the Dijkstra algorithm. GSR exhibits improved packet delivery ratio and scalability compared to AODV and DSR. Nevertheless, it may struggle in sparse networks with insufficient forwarding nodes and incurs higher routing overhead compared to GyTAR.

3.5. Anchor-Based Street and Traffic Aware Routing (A-STAR)

A-STAR is a position-based routing protocol designed for inter-vehicle communication in city scenarios. It leverages vehicular traffic and city bus information to ensure high connectivity in packet delivery. A-STAR is effective in low traffic density situations and employs a localized recovery strategy. However, its packet delivery ratio is lower than GSR and GPSR, and it relies on static city bus route information, which can lead to connectivity problems on certain street segments.

3.6. Street Topology Based Routing (STBR)

STBR represents a street map as a planar graph and categorizes nodes as master, slave, and forwarder. It minimizes the number of junctions crossed for long-distance unicast communication. However, STBR is not suitable for mixed scenarios and has increased complexity in special cases, such as transferring the neighbor table when a master node leaves the junction.

4. Cluster-Based Routing Protocol

Cluster-based routing protocols establish clusters among nodes or vehicles, with one cluster head responsible for intra- and inter-cluster communication. Examples include HCB, CBDRP, CBLR, CBR, etc.

4.1. Hierarchical Cluster-Based Routing (HCB)

HCB utilizes a two-layer communication architecture for highly mobile ad hoc networks. Layer-1 nodes communicate via multi-hop paths, while Layer-2 nodes communicate through a base station. Advantages include independent intra-cluster routing and periodic inter-cluster routing. However, HCB suffers from high packet loss and retransmissions.

4.2. Cluster-Based Directional Routing Protocol (CBDRP)

CBDRP is designed for vehicles moving in the same direction. It considers vehicle direction and velocity to route packets to the cluster header within the same cluster, ensuring reliable and rapid data transfer. Disadvantages include average control packet overhead and increased packet retransmissions.

4.3. Cluster-Based Location Routing (CBLR)

CBLR combines cluster-based and location-based approaches. Cluster heads maintain routing tables and track neighboring clusters. It selects the closest neighbor if they belong to the same cluster, otherwise broadcasts Location Request (LREQ) packets. CBLR is suitable for high mobility networks, utilizes digital maps, and has low control packet overhead. However, it may result in a high number of retransmissions.

4.4. Cluster-Based Routing (CBR)

CBR is a position and clustering-based routing protocol for VANETs. It divides the area into grids and uses geographical information for data forwarding. A cluster header broadcasts LEAD messages, and LEAVE messages are sent when the header exits the grid. Advantages include reduced routing overhead, but limitations include the lack of consideration for velocity and direction.

LORA-CBF is a variant of CBR that resembles greedy routing. It utilizes cluster heads and gateways for packet forwarding and exhibits heterogeneous performance results.

The Broadcast-Based Routing Protocol is a flooding-based protocol used to disseminate information among vehicles in VANETs. It aims to transmit accident or event information. However, broadcasting to all nodes can lead to collisions and bandwidth consumption. Various protocols like BROADCOMM, UMB, V-TRADE, DV-CAST, EAEP, SRB, PBSM, PGB, DECA, and POCA address these challenges.

5. BROADCOMM

BROADCOMM is a hierarchical routing protocol designed for Vehicular Ad Hoc Networks (VANETs) on highways. It divides the highway into virtual cells that move with the vehicles. The network has two levels of hierarchy, with all nodes in a cell at the first level and a subset of nodes serving as cell reflectors at the second level. Cell reflectors manage message exchange within their cells and facilitate forwarding with neighboring cell reflectors. BROADCOMM performs well in simple highway scenarios with few nodes, but its accuracy depends on the formation and configuration of virtual cells, which can limit its effectiveness.

5.1. Edge-Aware Epidemic Protocol (EAEP)

EAEP is a specialized protocol for message dissemination among vehicles that considers their geographical positions. It decides whether to rebroadcast a message based on the number of transmissions from preceding and succeeding nodes within a specific time period. However, EAEP does not address missed message detection. It reduces control packet overhead by eliminating hello packets and overcomes simple flooding issues. Nonetheless, it struggles with intermittent connectivity and results in high data transmission delays.

5.2. 5Distributed Vehicular Broadcast Protocol (DV-CAST)

DV-CAST classifies vehicles into three categories based on neighborhood connectivity: well connected, sparsely connected, and totally disconnected. It employs different strategies for each category. Well-connected neighborhoods use a persistence scheme, sparsely connected neighborhoods enable prompt rebroadcasting, and totally disconnected neighborhoods store messages until another vehicle comes within transmission range. DV-CAST employs a flag variable to identify packet redundancy. Its strengths lie in packet redundancy detection, but it exhibits high control overhead and end-to-end data transfer delays.

5.3. Secure Ring Broadcasting (SRB)

SRB classifies nodes into three groups based on receiving power: inner nodes, outer nodes, and secure ring nodes. Inner nodes are close to the sender, outer nodes are farther away, and secure ring nodes are optimally positioned. SRB minimizes retransmission messages, resulting in more stable routes. However, it incurs high control packet overhead.

5.4. Parameterless Broadcasting in Static to Highly Mobile Wireless Ad Hoc (PBSM)

PBSM is a parameterless broadcasting protocol that eliminates redundant broadcasting by using connected dominating sets (CDS) and neighbor elimination. It maintains two lists of neighboring vehicles (R and NR) to track packet reception. PBSM doesn't consider vehicle position or velocity but incurs high control packet overhead.

5.5. Preferred Group Broadcast (PGB)

PGB addresses broadcast storm issues during route request broadcasting. It sends the rebroadcast message to the node with the shortest timeout based on signal strength levels. PGB reduces the number of route request broadcasts but is not reliable.

5.6. Urban Multi-hop Broadcast Protocol (UMB)

UMB resolves collision and hidden node problems in multi-hop broadcasts. The sender selects the furthest node in the broadcast direction for forwarding and acknowledging the packet. UMB performs well in high packet load and traffic density scenarios but results in bandwidth wastage.

5.7. Vector-Based Tracing Detection (V-TRADE)

V-TRADE is a GPS-based message broadcasting protocol that categorizes neighbors into forwarding groups. Only a subset of vehicles from each group rebroadcasts the message, improving bandwidth utilization. However, it incurs routing overhead in selecting the next forwarding node.

5.8. Density-Aware Reliable Broadcasting Protocol (DECA)

DECA selects the neighbor with the highest local density for broadcasting without requiring position knowledge. It includes received broadcast messages in periodic beacons to identify unreceived messages. DECA does not need position knowledge but may result in message rebroadcasts if all nodes fail to identify a rebroadcasting candidate.

6. Geocast-Based Routing Protocol

Geocast routing is a location-based multicast protocol for sending messages to vehicles in a predefined geographic region, known as the Zone of Relevance (ZOR). Various Geocast routing protocols include IVG, DG-CASTOR, and DRG.

6.1. Inter-Vehicle Geocast (IVG)

IVG is a Geocast routing protocol for safety message dissemination on highways. It uses a timer-based mechanism and periodic broadcasts to overcome fragmentation. IVG is reliable but incurs high delay, control packet overhead, and retransmissions.

6.2. Robust Vehicular Routing (ROVER)

ROVER is a Geocast-based routing protocol that sends messages to vehicles within a specified ZOR. It uses broadcasts for control packets and unicasts for data packets. ROVER is reliable but suffers from high delay, control packet overhead, and retransmissions.

6.3. Dynamic Time-Stable Geocast Routing (DTSG)

DTSG is designed for sparse density networks with a pre-stable phase for message dissemination and a stable period using store and forward. It dynamically adjusts network density and vehicle speed but may result in a high number of retransmissions.

7. Conclusion

This paper explores the strengths and weaknesses of various routing protocols for vehicular communications in VANET. Existing protocols are insufficient for all traffic scenarios, necessitating the design of more efficient protocols. Performance evaluation is crucial to compare protocols and propose new solutions for VANET. Understanding the features of different protocols is essential for designing improved VANET routing protocols.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to disclosed.

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