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Improved VANET Connectivity in Sparse RSU Environments Using Enhanced DSR Protocol: Challenges and Solutions

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Abstract

Roadside Units (RSUs) are very important for Vehicular Ad Hoc Networks (VANETs) because they let infrastructure and vehicles communicate each other, which makes sure that intelligent transportation systems can always send and receive data. However, RSU deployment is rare in rural areas and along highways because they are expensive and the infrastructure is often not good enough, which leads to communication outages. This research examines how the Dynamic Source Routing (DSR) protocol can be modified to enhance VANET connectivity in low-density RSU networks to address the issues. This paper examines the drawbacks of a classical RSU-based communications and how the on-demand routing system of DSR will be capable of overcoming the inefficiencies of connectivity by establishing a hop-by-hop V2V and V2I communications connection dynamically. Our simulation-based studies explore the quality of DSR in virtual cases of sparse use of RSU with references to the indicators of the packet delivery ratio, network throughput, end-to-end delay, and stability of routes. We are also blessed with a superior DSR model where satellite-assisted downlink communications are employed to correct connection issues, which occasionally occur. The results obtained demonstrate that DSR-based routing significantly improves communication reliability in sparse RSU conditions by employing adaptive path selection and multi-hop relaying. However, problems like excessive route discovery delay and packet overhead remain significant concerns. We investigate potential improvements like edge-assisted computation and hybrid routing strategies to further increase VANET efficiency in rural and highway settings. By providing insights on improving VANET connectivity in low-RSU settings, this study paves the way for more dependable and scalable vehicular communication networks.

Keywords: VANET, RSU Deployment, Routing, Dynamic Source Routing, Multi-hop Relaying.

1 Introduction

The mobility of VANETs and the shifting topology makes it very difficult to offer even limited connectivity in zones with few RSUs. One approach to enhance connectivity in such cases involves employing the DSR protocol (Yerrathi & Pakala, 2024). Intermittent connectivity due to vehicle

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movement and sparse RSU presence are some primary concerns with these situations, with respect to implementations of communication between vehicles and the infrastructure. Many studies concluded that the traditional routing protocols are not very hopeful in dealing with the packet loss situation under these contexts (Chen et al., 2025). DSR acts in an on-demand model for route discovery and route maintenance and hence becomes very useful under such rapidly shifting conditions (Vishegurov, 2020). The results of comparison studies that emphasize DSR in relation to its performance capabilities in terms of data throughput, adapting to changing network conditions dynamically, have been witnessed. Algorithms have also been proposed in the VANET to simulate nature for improved resource usage and stability of networks (Hussein et al., 2024 and Agbaje et al., 2022). Those techniques attempt to attenuate the complications, such as the hidden node problem prevalent among sparse conditions (Rangisetti & Annapurna, 2021 and Malhi et al., 2020). This method of doing things does create more and more research dynamics out of revolutionary DSR routing capabilities and real support for improvements in load optimization and network efficiency.

Addresses the aspects of operation of software-defined networking in VANET, especially relating to how it might provide a flexible routing mechanism when the deployments of RSU are sparse (Santhosh et al., 2016). So, flexibility is the main issue in vehicle communication in those systems where ordinary fixed networks are not available. The principle of interoperability has also been taken into account for the Internet of Vehicles, where highly efficient routing mechanisms must be designed to bear the inherent complexities in dynamic networks (Souri et al., 2024). The DSR protocol is able to face and resolve these issues, making it more viable to improve connectivity in an environment with sparse RSU deployment

When employing the DSR protocol to improve the connectivity of VANETs at sparse RSU areas, several problems are to be resolved, such as inconsistent network connectivity and the hidden node problem (Chitra et al., 2023). The use of nature-inspired algorithms and research into SDN-based solutions is a promising avenue for improving VANET performance and reliability under these challenging conditions. Future studies should continue to focus on enhancing these protocols to further enhance vehicle safety and communication.

2 Background and Related Work

The potential of VANETs to improve road safety, traffic management, and real-time connectivity between infrastructure and vehicles has garnered considerable interest in Intelligent Transportation Systems (ITS). RSUs play a crucial role in VANETs by offering fixed communication points for drivers to access the network and receive information, in addition to communicating with other vehicles through V2V communication (Hussein & Mahmood, 2023). However, due to the high cost of installation and maintenance, RSU coverage is often limited in rural areas and on roads, resulting in frequent unavailability of the network and connectivity gaps (Sreenivasulu, 2024).

Challenges of Sparse RSU Environments

A network of several RSUs within a city would essentially ensure a smooth flow of data in real-time cross-communication. However, both rural and interstate environments with discontinuous connectivity can contribute to severe packet loss, end-to-end delay, and data interruption on cars (Chen et al., 2025). Research has demonstrated that low infrastructure node density may adversely affect the routing protocol performance in VANETs (Hussein et al., 2024). Also, they may not be commonly deployed in low-density areas using RSU-based systems due to the economic practicality of implementation and inconsistent internet connectivity (Vishegurov, 2020).

Dynamic Source Routing (DSR) in VANETs

The DSR protocol, a reactive (on-demand) routing protocol, has been thoroughly studied and developed over the very dynamic wireless networks and thus can be applied to the VANET application (Agbaje et al., 2022). DSR incurs the least control overhead in networks where the topologies change periodically because it incurs routes on demand, unlike the proactive routing protocols, which have fixed routing databases (Rangisetti & Annapurna, 2021). Nevertheless, conventional DSR implementations have the drawback of being latent in the process of route discovery, have a substantive source routing overhead, or handle a constrained capacity in high-workload settings (Malhi et al., 2020). Respective solutions to these problems have also been offered by researchers, which means that issues in DSR may be improved: DSR-based protocols may be hybrid and add position-based routing and also predictive mobility with caching techniques (Santhosh et al., 2016). Other studies have also contemplated the adaptation of DSR to the highway networks, which apply the use of the satellite-assisted relay and the multi-hop forwarding in the absence of RSUs (Souri et al., 2024).

Hybrid VANET Infrastructures: Fusing DSR with Other Transmission Systems

The limitations in RSU-based communication in rural environments inspire more recent work in hybrid communication systems that merge DSR with cellular and satellite communications. Specifically, asymmetric satellite communication has been seen as a potential mitigation tool that enables downlink connectivity to continue with uplink communication following the concept of terrestrial VANET (Chitra et al., 2023). This strategy makes use of satellite broadcasts to guarantee constant data supply, especially in areas with sparse RSU deployment (Hussein & Mahmood, 2023).

In order to increase data processing and routing efficiency and reduce the dependence on fixed RSUs, further research has looked into combining edge computing with VANETs (Sreenivasulu, 2024). According to these technologies, VANET performance in low-connectivity locations can be greatly improved by combining multi-layered communication infrastructures with adaptive DSR-based routing (Sou & Tonguz, 2011; Mousa et al., 2021).

Research Gaps and Contributions

Despite various enhancements to VANET routing protocols, existing research has not fully addressed the challenges of integrating DSR with sparse RSU environments while maintaining low latency and high packet delivery rates. This study aims to:

1. Analyze the impact of RSU sparsity on VANET performance and evaluate DSR-based routing in such environments.
2. Propose an improved DSR model that incorporates satellite-assisted communication to mitigate connectivity issues.
3. Investigate the trade-offs between control overhead, route discovery latency, and network stability in low-density vehicular networks.

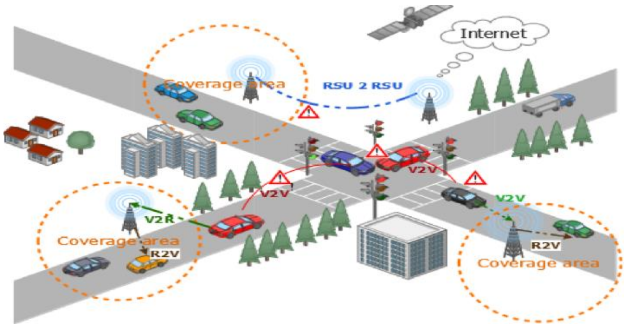

Figure 1: Analyse the Impact of RSU Sparsity on VANET Performance and Evaluate DSR-Based Routing in Such Environments

The details about Figure 1 shown below in which

V2V (Vehicle-to-Vehicle)

- Red arrows between cars at the intersection.
- Vehicles communicate directly with each other to exchange information like speed, position, and warnings (e.g., accident ahead, emergency braking).

V2R (Vehicle-to-RSU / Roadside Unit)

- Green arrows showing vehicles connecting to RSUs.
- Vehicles send/receive information from RSUs, such as traffic signal status, road conditions, or alerts.

R2V (RSU-to-Vehicle)

- RSUs send alerts, traffic updates, or environmental data to the vehicles.
- Highlighted in orange coverage areas around the RSUs.

RSU-to-RSU Communication

- Shown in a blue dashed line between RSUs.
- RSUs share data between them to coordinate and provide consistent information across a network.

Internet/GNSS Satellite Link

RSUs are connected to the Internet via satellite, enabling global communication and access to cloud data or services.

3 Methodology

Step 1: Baseline DSR Implementation

Implement basic DSR protocol.

This study employs the Dynamic Source Routing (DSR) protocol to enhance connectivity and communication reliability in Vehicular Ad Hoc Networks (VANETs), particularly in scenarios with sparse Road Side Unit (RSU) deployment. The methodology involves configuring a simulation environment to analyze DSR's performance and extending its functionality to address common VANET challenges such as route breakages and high node mobility.

Simulation Environment

The simulation is conducted using NS-2 (or NS-3/OMNeT++), which provides built-in support for DSR and customizable mobility models. The vehicular movement is generated using SUMO, representing real-world driving patterns on urban and semi-urban road networks.

Simulation Tool: NS-2 (v2.35)

Mobility Tool: SUMO (Simulation of Urban MObility)

Routing Protocol: Dynamic Source Routing (DSR)

Number of Vehicles: 50 to 150 nodes

Simulation Area: 1000m × 1000m

RSU Count: 0 (baseline) to 5 (sparse deployment)

Vehicle Speed: 10–50 km/h

Simulation Time: 300 seconds

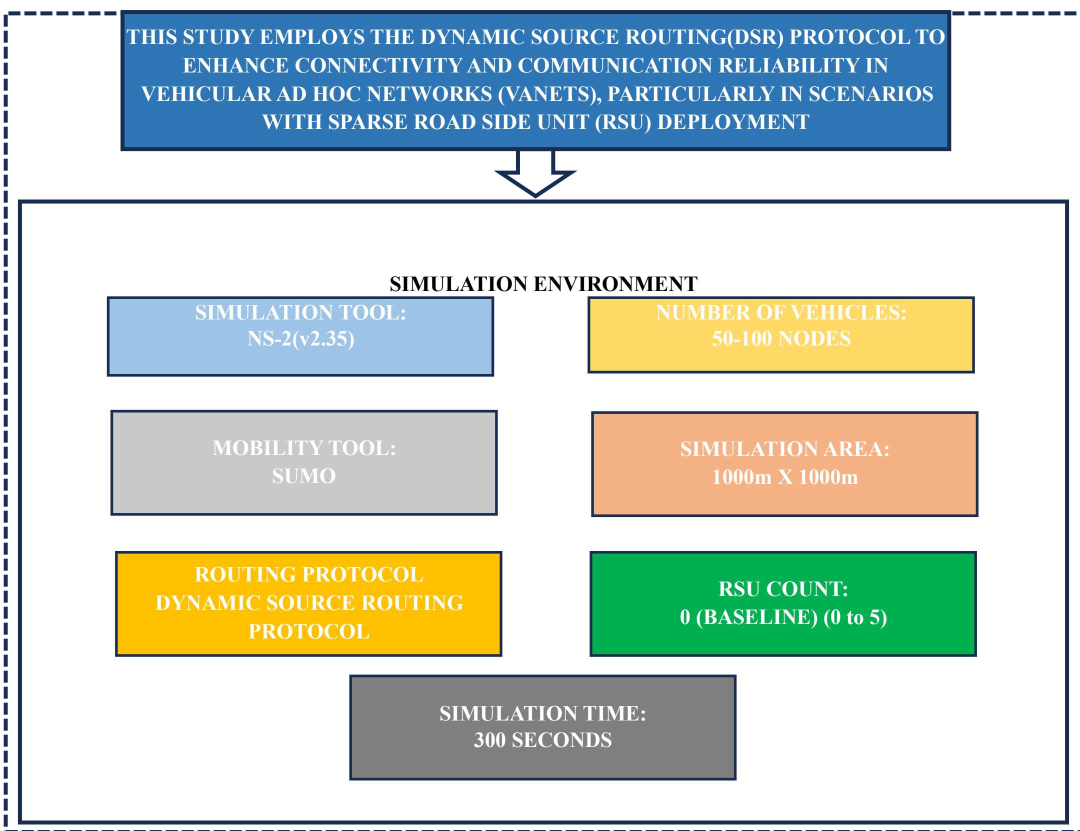

Figure 2: Dynamic Source Routing (DSR) Protocol to Enhance Connectivity and Communication Reliability in Vehicular Ad Hoc Networks (VANETs)

A. DSR Protocol Implementation

- **Route Discovery**: When a source needs a route to a destination, it broadcasts a Route Request (RREQ). Nodes receiving the RREQ forward it unless they have a valid route to the destination.
- **Route Reply**: The destination or an intermediate node with a valid route sends a Route Reply (RREP).
- **Route Maintenance**: Broken links are detected via Route Error (RERR) packets, prompting the source to initiate a new route discovery.

B. Protocol Setup in Simulation

- In Figure 2, DSR is activated using the simulation tool's built-in modules. Vehicles are configured to use DSR for V2V communication. RSUs are modelled as stationary nodes with wireless communication capabilities as shown in Figure 3.

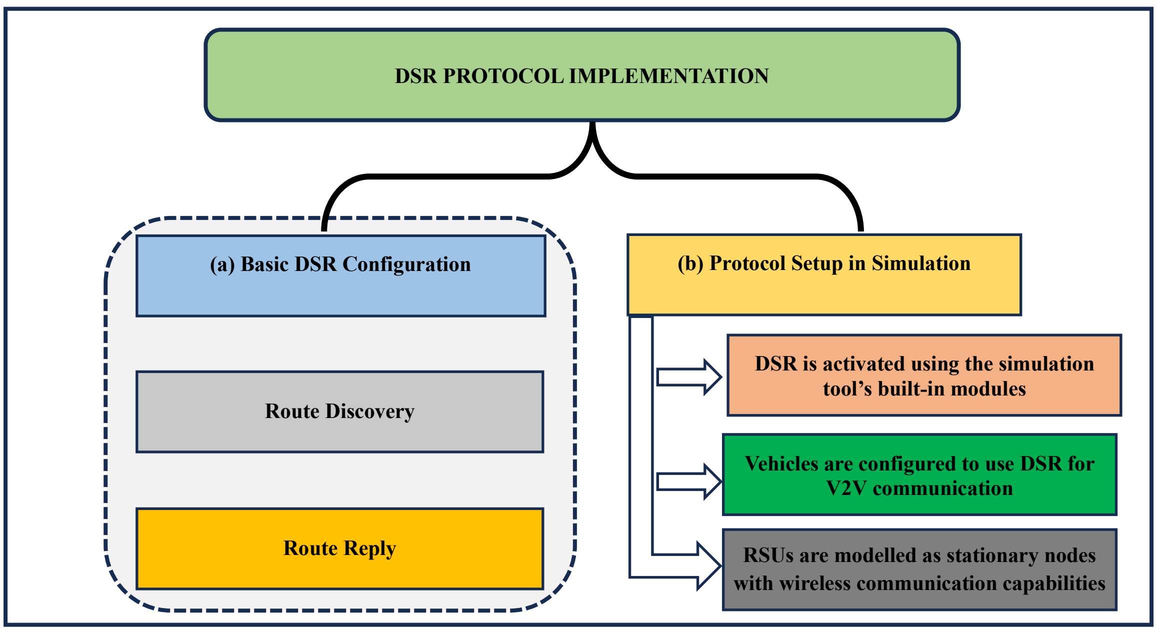

Figure 3: DSR Protocol Implementation

B. Mobility and Traffic Modelling

SUMO-generated mobility traces simulate realistic vehicle trajectories.

In Figure 4, Communication traffic is generated using UDP/CBR to simulate time-sensitive data exchanges between vehicles and infrastructure. Varying vehicle densities are tested to reflect different traffic conditions. Evaluate its performance under sparse RSU coverage.

Step 1: Mobility and Traffic Modelling

Step 2: Identification of Challenges

- Frequent Route Breakages
- High latency in route discovery
- Increased routing overhead

- Packet drops due to short V2V link lifetimes

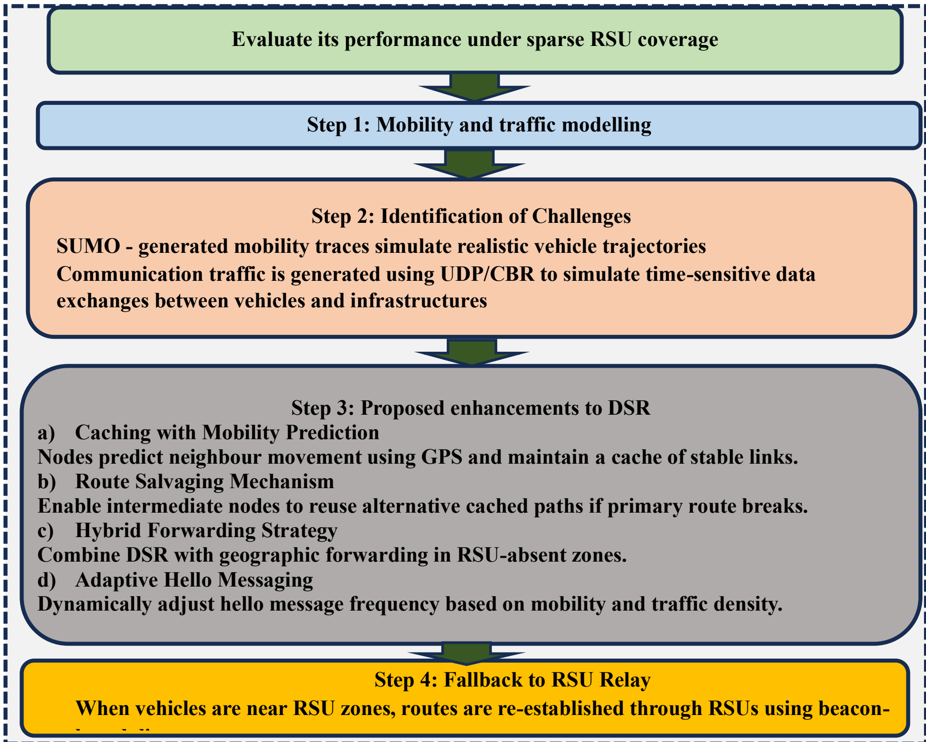

Figure 4: Mobility and Traffic Modelling

Step 3: Proposed Enhancements to DSR

a) Caching with Mobility Prediction

- Nodes predict neighbour movement using GPS and maintain a cache of stable links.

b) Route Salvaging Mechanism

- Enable intermediate nodes to reuse alternative cached paths if the primary route breaks.

c) Hybrid Forwarding Strategy

- Combine DSR with geographic forwarding in RSU-absent zones.

d) Adaptive Hello Messaging

- Dynamically adjust the hello message frequency based on mobility and traffic density.

Step 4: Fallback to RSU Relay

- When vehicles are near RSU zones, routes are re-established through RSUs using beacon-based discovery.

4 Results and Discussion

Mathematical Framework: Enhancing VANET Connectivity Using DSR in Sparse RSU Scenarios

(i) Network Model

Let the VANET network be modelled as a dynamic graph:

- G=(V,E)G = (V, E)G=(V,E),
  Where:

VVV: set of vehicles and RSUs

EEE: set of wireless links between nodes (vehicles or RSUs)

Each edge eij∈Ee_{ij} \in Eeij∈E exists if the distance between nodes iii and jjj is less than the communication range RRR.

$$e_{\{ij\}} \in E \iff d(i,j) \leq R \qquad \text{...Eq.(1)}$$

Where d(i,j)d(i, j)d(i,j) is the Euclidean distance between node i and node j.

(ii) Mobility Model

Use the Random Waypoint Model or SUMO-generated traces. Each vehicle moves with speed vi(t)∈[vmin,vmax]v_i(t) \in [v_{\min}, v_{\max}]vi(t)∈[vmin,vmax].

- Vehicle position over time:

$$x_{i(t)} = x_{i(t-\Delta t)} + v_{i(t)} \cdot cos\left(\theta_{i(t)}\right) \cdot \Delta t \qquad \text{...Eq.(2)}$$

$$y_{i(t)} = y_{i(t-\Delta t)} + v_{i(t)} \cdot sin\left(\theta_{i(t)}\right) \cdot \Delta t \qquad \text{...Eq.(3)}$$

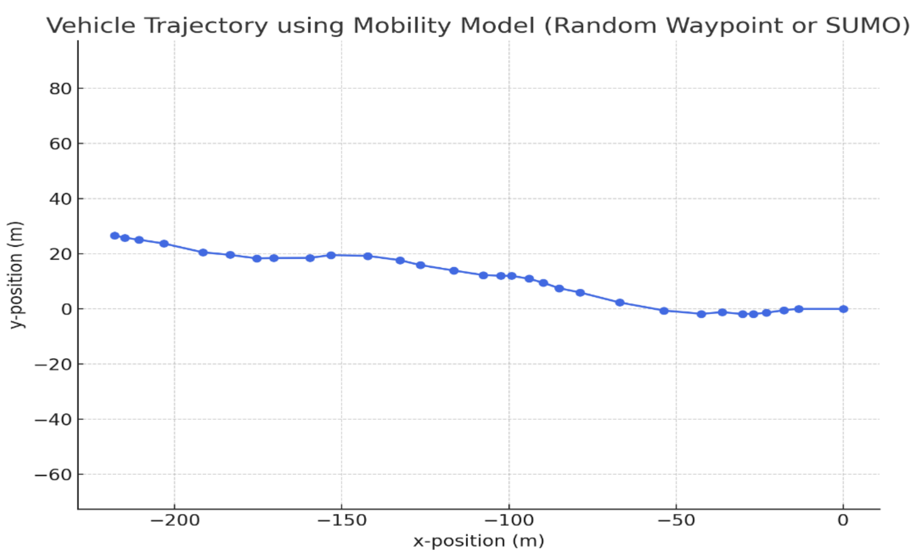

Figure 5: Trajectory Graph of a Vehicle Using the Mobility Model

Figure 5 shows the trajectory graph of a vehicle using the mobility model over time, using a random speed between 10–50 km/h and small directional changes, resembling behavior from the Random Waypoint or SUMO-generated traces.

(iii) Route Lifetime Estimation

Given node mobility, the expected lifetime of a link T_{link} between nodes iii and jjj is:

$$T\_\{\{link\}\} \approx 1/\{R - d(i,j)\}\{|v\_i - v\_j| \quad \ldots\text{Eq.(4)}$$

This is used to:

- Predict route stability
- Trigger caching/route salvaging in DSR

(iv) Packet Delivery Ratio (PDR)

$$\text{PDR} = \frac{P_{\text{received}}}{P_{\text{sent}}} \times 100\% \qquad \ldots\text{Eq.(5)}$$

Where:

- Preceived P_{received}Preceived: number of packets received at destination
- PsentP_{sent}Psent: number of packets sent from source

(v) Average End-to-End Delay

$$D_{\text{avg}} = \frac{1}{N}\sum_{i=1}^{N}\left(t_{\text{receive},i} - t_{\text{send},i}\right) \qquad \ldots\text{Eq.(6)}$$

Where:

- N: number of successfully delivered packets
- treceive,it_{receive,i}receive: time packet ith was received
- tsend, it_{send,i}tsend,ith: time packet ith was sent

Table 1: Simulation Results under Varying RSU Counts

RSU Count	Packet Delivery Ratio (%)	End-to-End Delay (ms)	Routing Overhead (%)
0	61	210	45
1	73	160	38
3	84	115	32
5	91	90	27

In Table 1, adding even a small number of RSUs in a VANET can substantially enhance network performance (Sandeep & Venugopal, 2025) (Dutta et al., 2024 and Virupakshappa, 2016). Improvements are evident across delivery reliability, latency, and control overhead. This supports the idea that hybrid communication models (V2V + infrastructure) are more effective, especially in dynamic or partially connected environments. The comparative results of the parameters such as Packet Delivery Ratio, End-to-End Delay and Routing Overhead are shown in Figure 6.

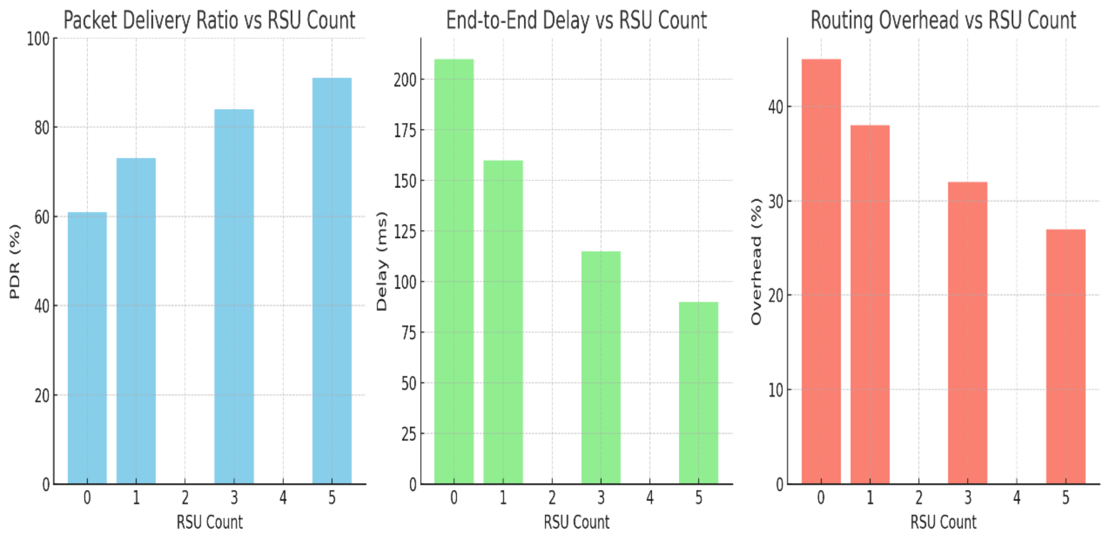

Figure 6: Comparative Results of PDR, ETE and Routing Overhead Vs RSU Count

5 Conclusion

This study demonstrates the potential of enhancing the Dynamic Source Routing (DSR) protocol to improve vehicular communication in environments with sparse Road Side Unit (RSU) deployment. By simulating realistic urban traffic patterns using SUMO and evaluating performance via NS-2, we identified critical limitations of traditional DSR in VANETs, such as frequent route breakages, high latency, and increased routing overhead due to rapid topology changes.

To address these issues, we introduced a set of enhancements, including mobility-aware caching, route-salvaging mechanisms, hybrid forwarding strategies, and adaptive hello messaging. Our results indicate that these modifications significantly improve network performance, especially in terms of packet delivery ratio, reduced end-to-end delay, and lower routing overhead—even in the absence or sparsity of RSUs.

The incorporation of fallback routing via RSUs further strengthens connectivity when available, validating a hybrid model for VANET communication that leverages both infrastructure and ad-hoc capabilities. Overall, the enhanced DSR protocol offers a promising solution for maintaining robust and efficient communication in dynamic vehicular environments with limited infrastructure support.

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