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Hakimeh Azimi
Shahid Bahonar University of Kerman
Vahid sattari Naeini
Shahid Bahonar University of Kerman
Omid Abedi
oabedi@uk.ac.ir

Shahid Bahonar University of Kerman

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Vehicle-to-Infrastructure Connectivity Improvement Based on Heterogeneous Networks in Intelligent Transportation Systems

Hakimeh Azimi[1] . *Vahid Sattari-Naeini*[1] . *Omid Abedi*[1]*

Abstract

Selecting the right roadside unit (RSU) is an important issue in heterogeneous vehicular networks, especially when vehicles move quickly and link stability matters more than short-term performance peaks. In many existing association methods, decisions are made mainly based on signal strength or instantaneous data rate, which often results in frequent handovers and unstable connections. To address this problem, we propose a quality-of-service-aware RSU association framework that takes into account dwell time, communication delay, and the expected amount of data that can be transmitted during the connection period. The proposed method estimates how long a vehicle is likely to remain within the coverage of each candidate RSU and then selects the most suitable one based on service requirements. Simulation results show that this approach can greatly reduce handovers and improve connection continuity compared with conventional greedy methods. Although this comes with a moderate trade-off in throughput and delay, the overall performance is better suited to dense and highly dynamic vehicular environments.

Keywords Intelligent Transportation Systems, Connectivity, Heterogeneous networks, Vehicle to Infrastructure Communication

1 Introduction

Vehicular Ad Hoc Network (VANET), as one of the key components of the Intelligent Transportation System (ITS), plays an essential role in enhancing road safety, improving traffic efficiency, and providing advanced services to passengers and drivers. With the development of VANET, vehicles have become intelligent communication nodes and can dynamically and in real time transfer information among vehicles and road infrastructure, which has led to a transformation in urban transportation infrastructure [1]. VANET facilitates the exchange of safety-related information, such as vehicle location and speed, which supports cooperative awareness and enables real-time warnings [2]. Vehicles and RSUs can reduce travel times and better manage traffic by leveraging real-time data exchange to enhance traffic flow and routing efficiency in dynamic environments [3, 4]. VANETs support content-delivery and communication services for vehicles and their users, enabling Internet-oriented access, infotainment, and passenger information services [5]. In addition, VANET-based communication infrastructures contribute to emerging autonomous vehicle technologies and real-time vehicular applications [6, 7]. Therefore, with the evolution of vehicular networks, maintaining reliable connectivity and communication quality becomes a research challenge in intelligent transportation systems.

The development of communication technologies such as DSRC/802.11p [8], LTE/5G, together with the deployment of smart infrastructures, has enabled the creation of heterogeneous Vehicular Ad Hoc Networks

[1] *Department of Computer Engineering*
Shahid Bahonar University of Kerman, Kerman, Iran

✉ *Omid Abedi*
Email: oabedii@uk.ac.ir

(heterogeneous VANETs). In such networks, vehicles can utilize multiple communication technologies to improve communication reliability. By combining short-range technologies such as DSRC with long-range technologies such as LTE and 5G, heterogeneous VANETs enhance the quality and stability of communication in traffic conditions and complex urban environments [9].

Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) are two key types of communication in Vehicular Ad Hoc Networks (VANETs) that play a crucial role in improving road safety and enhancing the performance of intelligent transportation systems. V2V communication enables the direct exchange of data between vehicles, providing real-time warnings about traffic conditions, obstacles, and potential hazards. In contrast, V2I communication refers to the interaction between vehicles and roadside infrastructure such as Roadside Units (RSUs), which support various services including traffic management, sensor data transmission, smart traffic light control, and infotainment services [10].

In urban environments, sustainable Vehicle-to-Infrastructure (V2I) communication is considered one of the key pillars of intelligent transportation systems and plays an important role in improving road safety and reducing traffic accidents [11, 12]. In dense urban traffic conditions, reliable V2I communication can reduce data transmission delays, enhance communication reliability, and improve the quality of time-sensitive services such as safety alerts and advanced driving assistance systems [11, 13]. Accident prevention and management represent one of the most important applications of V2I communication, enabled by the real-time exchange of data between vehicle sensors and roadside infrastructure [11, 12]. V2I systems facilitate rapid responses from drivers and autonomous vehicles by delivering warning messages related to traffic situations and hazardous conditions, thereby helping to reduce traffic accidents [13]. Moreover, stable and high-quality V2I connectivity supports the development of autonomous vehicles, which require continuous and reliable communication for fast and accurate decision-making [11]. By exchanging real-time information such as traffic conditions, road status, and smart traffic signal data, V2I communication contributes to more efficient traffic management and helps prevent unnecessary congestion and delays. This capability can reduce travel time, decrease fuel consumption, and mitigate air pollution. Ultimately, V2I communication represents a fundamental component in the development of smart cities and sustainable transportation systems [14]. Therefore, improving the sustainability and reliability of vehicle-to-infrastructure connectivity in urban environments is an important research direction with significant technological, economic, and societal implications.

Despite the significant potential of Vehicular Ad Hoc Networks (VANETs) to improve urban transportation efficiency and road safety [15], these networks still face several connectivity challenges. One of the most important issues is the frequent disconnection and reconnection of communication links [16]. Due to the high mobility of vehicles, constant topology changes, and the rapid movement of vehicles beyond the communication range, links are often interrupted and the connection between vehicles and infrastructure or other vehicles becomes unstable [3].

Furthermore, the use of wireless communication and the large number of mobile nodes may lead to sudden network congestion and reduced effective link capacity. As a result, the response time of services increases, making transmission delay a critical challenge in VANET environments. In addition, the limited number of Roadside Units (RSUs) or their inefficient deployment can prevent services from being delivered effectively. Consequently, vehicles may lose connectivity, and certain road segments or urban areas may experience communication coverage gaps [17].

In scenarios where vehicles move at high speeds or where mobile roadside units are deployed (such as RSUs installed on city service vehicles or police cars), maintaining reliable vehicle-to-infrastructure connectivity in heterogeneous environments becomes a significant challenge. Moreover, optimizing network resources and ensuring quality of service (QoS) is difficult in environments where multiple heterogeneous communication technologies and diverse infrastructure components coexist. Therefore, advanced models and algorithms are required to improve connectivity and service reliability in such heterogeneous vehicular environments [18]. This research investigates the optimal selection of a Roadside Unit (RSU) for vehicles in a heterogeneous vehicular network to support the transmission of high-quality and low-latency data streams. Each vehicle may generate different classes of data streams, such as multimedia, voice, text, or control and safety-related data. The RSU selection process should ensure that quality of service (QoS) constraints, including minimum link rate and maximum latency, are satisfied while maximizing the amount of data that can be transmitted during the time a vehicle remains within the communication range of the RSU.

The remainder of this paper is organized as follows. Section II reviews the related work. Section III presents the proposed methodology. Section IV describes the simulation setup and discusses the results. Finally, Section V concludes the paper.

2 Related Work

2.1 Static, Mobile, and Hybrid RSU Deployment

Recent advances in heterogeneous vehicular networks (HetVNETs) have motivated extensive research on RSU deployment, connectivity optimization, and intelligent association mechanisms. Karunathilake et al. [19] provided a comprehensive review of mobile RSUs (mRSUs) in vehicular networks. The study categorizes mRSUs based on various deployment scenarios, such as public buses, police vehicles, and taxis, while evaluating the trade-offs between static and mobile infrastructures. The authors highlight that while static RSU coverage is predictable, inherent limitations in cost and deployment density often lead to intermittent connectivity. Conversely, mRSUs offer flexible and cost-efficient coverage; however, they introduce significant uncertainty regarding stopover times and connection durations. Building upon these findings, our work addresses the need for an adaptive RSU selection mechanism that dynamically ranks infrastructure based on spatiotemporal factors, including latency, achievable data rates, and predicted dwell times

Guerna et al. [17] studied RSU deployment and planning in the Internet of Vehicles (IoV) context. They compared fixed, mobile, and semi-mobile RSU configurations and assessed them using common indicators such as latency, reliability, and coverage. One key observation in their analysis is that many existing formulations concentrate mainly on coverage maximization or cost reduction, whereas the interaction between communication delay and network capacity is often treated only superficially. They also argue that heterogeneous V2X settings—spanning DSRC, LTE, 5G, and C-V2X—call for more adaptive decision mechanisms, where RSU selection is driven by multiple dimensions (e.g., achievable link rate and transmission capability) rather than a single dominant objective.

In a related direction, Li et al. [20] proposed a hierarchical deployment architecture that combines stationary RSUs with parked vehicles operating as temporary RSUs (t-RSUs). The scheme aims to increase urban coverage while limiting infrastructure cost by activating parked cars as needed. SUMO-based simulations reported in [20] indicate that this hybrid strategy can improve connectivity and reduce latency compared with purely static deployments. This opportunistic use of vehicles is consistent with our underlying assumption that public buses and emergency vehicles can play the role of mobile RSUs. In addition, their hierarchical decision process offers a useful reference point for our RSU ranking design, which jointly considers latency, data rate, and predicted dwell time.

2.2 Optimization-Based RSU Deployment

Yu et al. [21] proposed an optimization framework for RSU deployment in urban VANETs based on the Non-Dominated Sorting Genetic Algorithm II (NSGA-II). Their model jointly optimizes cost, coverage, and communication performance to identify Pareto-optimal deployment configurations. Using real traffic data and urban topology maps, the study demonstrates that balancing multiple conflicting objectives can substantially improve network performance. The approach presented in [21], particularly the integration of multi-objective optimization for RSU placement, provides useful insights for developing optimal deployment and ranking mechanisms. Building on these findings, the present research defines a multi-factor utility function incorporating effective delay, link rate, and transmission capacity within RSU coverage to enable dynamic prioritization between stationary and mobile RSUs.

2.3 Load-Aware and Heterogeneous Network Control

Marwein et al. [22] discussed the current state of load balancing in heterogeneous vehicular networks and presented a hierarchical system of distributing the load in SD-IoV via local and main SDN controllers along with fog and cloud computing. The study demonstrates that decision-making locally at the fog layer instead of forwarding all traffic to the main cloud-based controller improves response time and end-to-end delays when the heterogeneous network is experiencing heavy traffic. It is highly pertinent to this research as latency and communication responsiveness depend on the amount of traffic and the location of control decisions in multi-technology environments. Therefore, incorporating load-awareness and the hierarchy of decision-making while

ranking RSUs will improve the adaptability and scalability of heterogeneous vehicular networks.

2.4 Handover and Vertical Decision Models in Vehicular Networks

Agyare et al. [23] proposed an optimized vertical handover decision model for heterogeneous DSRC/LTE vehicular networks based on fuzzy logic. Their approach balances received signal strength (RSS), signal-to-interference ratio (SINR), and vehicle speed to minimize unnecessary handovers and communication delays through adaptive parameter weighting. Conceptually, this framework aligns with the proposed context-aware RSU selection strategy, in which decision variables correspond to performance metrics such as latency, link capacity, and temporal stability (e.g., predicted dwell time). Accordingly, weighted ranking mechanisms may provide an effective implementation framework for the proposed RSU selection model.

2.5 Multi-Criteria RSU Ranking Methods

Jain et al. [24] applied a hybrid Fuzzy-AHP and TOPSIS framework to rank RSUs by considering criteria such as road topology, traffic behavior, and communication technology. Their results showed that multi-criteria RSU selection can improve network coverage, enhance packet delivery performance, and reduce communication delay. Methodologically, this study is relevant to the present work because it demonstrates the effectiveness of structured multi-criteria decision-making for RSU evaluation.

Gu et al. [25] proposed a clustering-based strategy for RSU deployment that jointly considers connectivity, sensing capability, and edge computing support. Their work highlighted the importance of geographical distribution and vehicle dwell time in improving RSU service effectiveness, and it provides a useful basis for integrating fixed and mobile RSUs within a unified selection framework.

Luan et al. [26] investigated RSU deployment with the objective of reducing communication delay at highway intersections. Their findings indicated that delay minimization is a critical factor in RSU placement and selection, which is directly aligned with the effective delay criterion considered in the present study.

Kouonchie et al. [27] proposed an AI-based RSU deployment scheme for urban areas using a hybrid GA–PSO optimization approach. Their study demonstrated that deployment decisions significantly affect connectivity and end-to-end delay, which aligns with the delay-sensitive criteria considered in the present work.

2.6 Summary and Research Gap

Collectively, these studies reveal several outstanding research gaps. First, while significant research has focused on RSU deployment and static optimization, the challenge of real-time, context-aware RSU selection in dynamic environments remains underexplored. Second, most existing models evaluate connectivity within static or semi-dynamic contexts, often failing to account for the implications of mobile RSU infrastructure and the inherent variance in vehicle dwell time within coverage areas. Third, previous works have rarely integrated latency, link rate, and transmission capacity into a unified, multi-dimensional decision criterion. Addressing these gaps, the present study proposes a novel RSU ranking mechanism that jointly evaluates latency, link capacity, and transmission stability for both fixed and mobile RSUs. This holistic evaluation aims to enhance the robustness and continuity of connectivity in heterogeneous vehicular networks, offering a scalable and adaptive solution for next-generation V2I communication systems.

3 Proposed QoS-Aware RSU Association Framework

3.1 Problem Overview

The aim of this study is to select the appropriate RSU for high-quality and stable data transmission in an urban vehicular network consisting of fixed and mobile RSUs, as illustrated in Fig. 1. This figure provides an overview of the RSU deployment architecture and the Manhattan-based vehicular movement pattern.

The main objective of this work is to improve vehicle connectivity in heterogeneous vehicle networks (HetVNETs) by selecting the most suitable roadside unit (RSU) for each vehicle. The proposed method ranks candidate RSUs based on three key criteria of predicted data rate during expected dwell time, communication delay, and the effective application-layer link rate. Recent studies have shown that mobility-aware RSU selection mechanisms can significantly improve connectivity stability and service performance in vehicular networks [28]. Vehicular networks require efficient infrastructure

association mechanisms to maintain reliable connectivity under high mobility conditions [2].

Consider a vehicle of class c that needs to transmit a data stream of size $S^{(c)}$, while satisfying a minimum rate requirement $r_{\text{req}}^{(c)}$ and a maximum tolerable delay $L_{\text{req}}^{(c)}$. Let $\mathcal{I}$ denote the set of candidate RSUs available along the predicted vehicle trajectory. The objective is to select the RSU that best satisfies the service requirements under the predicted communication conditions.

The following subsections present detailed models and calculations for the vehicle-RSU dwell time, the expected transmittable data rate, and the communication delay, which together form the basis of our multi-criteria RSU selection algorithm. The main symbols used throughout this section are summarized in Table 1.

Table 1. Main notations

Symbol	Description	Unit
$\mathcal{I}$	Set of candidate RSUs along the predicted vehicle trajectory	–
$\mathcal{I}_0^{(c)}$	RSUs satisfying dwell-time and transferable-data conditions	–
$\mathcal{I}_1^{(c)}$	RSUs satisfying rate and delay QoS constraints	–
$r_{i,\text{nom}}$	Nominal PHY-layer data rate with RSU i	Mbps
$r_{\text{req}}^{(c)}$	Minimum required rate for service class c	Mbps
$T_{\text{dwell},i}$	Predicted dwell time in RSU i coverage	s
T_{setup}	Connection setup time before data transmission	s
$T_{\text{handover}}^{(c)}$	Minimum dwell time required for handover	s
$T_{\text{delay},i}^{(c)}$	Communication delay for service class c	s
D_i	Maximum transferable data during dwell time	Mb
$S^{(c)}$	Required data size for service class c	Mb
$w_T^{(c)}, w_R^{(c)}, w_D^{(c)}$	Weights for delay, rate, and data metrics	–
$H^{(c)}$	Handover hysteresis margin	–

In this work, two link-rate representations are considered. The nominal rate $r_{i,\text{nom}}$ denotes the PHY/MAC-layer capacity of the wireless link and is used to estimate the transferable data volume and transmission delay. The effective rate r_i, in contrast, denotes the application-layer throughput after accounting for protocol overhead and channel contention and is used in the RSU ranking process. Accordingly, each RSU i is characterized by $(r_{i,\text{nom}}, r_i, T_{\text{dwell},i}, C_i)$.

3.2 Network Architecture and Mobility Model

3.2.1 Mobility and Network Assumptions. The vehicle path follows the Manhattan mobility model, where vehicles travel only on streets and direction changes occur exclusively at intersections. In each street segment, the vehicle speed is assumed to be approximately constant to allow for analytical estimation of the dwell time within an RSU coverage area. In practice, vehicles may accelerate, stop, or change speed, which may reduce the accuracy of dwell time prediction. Therefore, this mobility model is a simplified assumption used to present the core idea of the proposed RSU selection algorithm and can be generalized in future work using stochastic mobility models.

Fixed RSUs are deployed along roadways to provide stable coverage [17], whereas mobile RSUs mounted on vehicles can offer adaptive coverage in high-demand areas. Vehicles are equipped with V2X modules and position sensors, enabling V2I communication with nearby RSUs. RSUs can also act as edge nodes providing communication and computation services to nearby vehicles [6]. Each RSU is modeled with a circular communication range of radius R_"RSU" and limited service capacity.

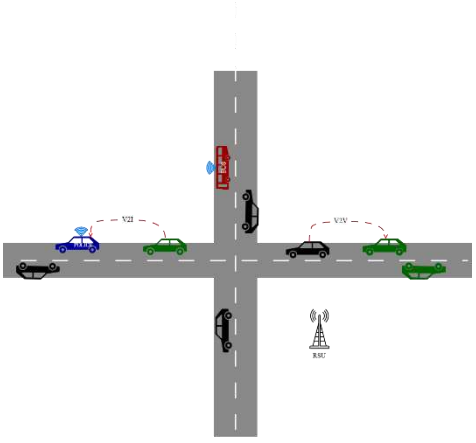


Fig. 1. Urban HetVNET architecture with fixed and mobile RSUs

3.3 Dwell Time Estimation

Dwell time indicates how long a vehicle remains within the acceptable communication range of an RSU (fixed or mobile). This duration may be limited for mobile

RSUs, such as those mounted on buses or service vehicles. Connecting vehicles to RSUs that are available only for a short time causes connection instability, increases the connection drop rate, and reduces the quality of service. Therefore, choosing the RSU with the longest dwell time increases the probability of maintaining a stable connection.

In this work, the vehicle–RSU dwell time is computed by modeling their relative motion. The relative position vector is defined as

$$\begin{aligned} \boldsymbol{p}_{\text{rel}}(t) &= \boldsymbol{p}_v(0) - \boldsymbol{p}_{\text{RSU}}(0) + (\boldsymbol{u}_v - \boldsymbol{u}_{\text{RSU}})t \\ &= \boldsymbol{p}_{\text{rel}}(0) + \boldsymbol{u}_{\text{rel}}t, \end{aligned} \tag{1}$$

where $\boldsymbol{p}_v(0)$ and $\boldsymbol{p}_{\text{RSU}}(0)$ are the initial positions, and $\boldsymbol{u}_v, \boldsymbol{u}_{\text{RSU}}$ are their respective velocities. A vehicle is within the coverage region when

$$\| \boldsymbol{p}_{\text{rel}}(t) \|^2 \leq R_{\text{eff}}^2, \qquad R_{\text{eff}} = \min(R_v, R_{\text{RSU}}) \tag{2}$$

where R_{eff} is the effective bidirectional communication radius.

The entry and exit times are obtained by solving the quadratic equation

$$at^2 + bt + c = 0, \tag{3}$$

with coefficients

$$\begin{aligned} a &= \| \boldsymbol{u}_{\text{rel}} \|^2, \\ b &= 2(\boldsymbol{p}_{\text{rel}}(0) \cdot \boldsymbol{u}_{\text{rel}}), \\ c &= \| \boldsymbol{p}_{\text{rel}}(0) \|^2 - R_{\text{eff}}^2. \end{aligned} \tag{4}$$

and the discriminant

$$\Delta = b^2 - 4ac. \tag{5}$$

Solving (3) yields the RSU entry and exit times, t_{in} and t_{out}. The vehicle–RSU dwell time is then computed as

$$T_{\text{dwell},i} = t_{\text{out}} - t_{\text{in}}. \tag{6}$$

A geometric interpretation of the dwell time interval is provided in Fig. 2.

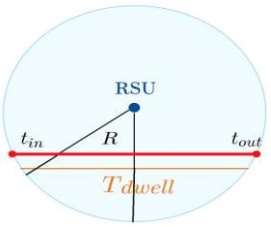


Fig. 2. Geometric representation of vehicle dwell time within the RSU coverage region

To analyze the initial interaction behavior, the relative motion direction is determined from the sign of the dot product in (4):

$$\boldsymbol{p}_{\text{rel}}(0) \cdot \boldsymbol{u}_{\text{rel}} = \begin{cases} < 0, & \text{approaching (vehicle moving toward the RSU),} \\ = 0, & \text{tangential (motion perpendicular to the boundary),} \\ > 0, & \text{receding (vehicle moving away from the RSU).} \end{cases} \tag{7}$$

This term directly influences the dwell-time computation through coefficient b in (4).

Because RSUs generally have higher transmission power than vehicles, it often holds that $R_{\text{RSU}} > R_v$, making R_{eff} primarily constrained by the vehicle range. Condition (2) therefore ensures that only physically admissible dwell-time windows are considered.

The dwell time is computed using a quadratic boundary-crossing model that naturally covers all physical edge cases (non-intersection, tangential contact, inside-start, and finite-horizon clipping).

3.4 Communication Performance Modeling

3.4.1 Transferable Data Model. The data rate metric serves as a complementary indicator for evaluating the link quality between vehicles and RSUs. The network dwell time is the time a vehicle remains within the coverage area of an RSU [29].

We classify the data streams into four categories: multimedia, voice, text, and control. These traffic classes exhibit different QoS requirements, particularly in terms of latency and minimum data rate, reflecting the heterogeneous service demands of V2X communications [30]. Indicative QoS requirements for the considered V2X service types are summarized in Table 2 [30]–[36].

Table 2. Indicative QoS requirements for V2X service types.

Data Type	Typical Data Rate	Latency Requirement
Multimedia	1–20 Mbps	50–100 ms
Voice	64–256 Kbps	20–100 ms
Non-safety (text)	< 100 Kbps	100–500 ms
Safety (CAM/DENM)	10–100 Kbps	20–100 ms

Different service classes may favor different RSU characteristics depending on their QoS requirements. Delay-sensitive traffic, such as control and safety messages, primarily prioritizes low communication latency and stable connectivity, whereas multimedia services tend to favor RSUs offering larger transferable capacity and higher effective throughput during the predicted dwell interval. Consequently, the proposed framework performs class-aware RSU selection by adapting the feasibility constraints and ranking process according to the parameters $(S^{(c)}, r_{\text{req}}^{(c)}, L_{\text{req}}^{(c)})$ associated with each service category. This allows the algorithm to dynamically select different RSUs for different application types, even under the same mobility conditions.

The effective amount of data that can be transferred during a contact can be approximated as the product of the achievable link rate and the effective connection time, following contact-duration-based models in vehicular and opportunistic networks [37, 38]:

$$D_i = r_{i,\text{nom}} \times \max\left(0,\ T_{\text{dwell},i} - T_{\text{setup}}\right) \tag{8}$$

where $r_{i,\text{nom}}$ is the nominal (or measured) link rate, $T_{\text{dwell},i}$ is the dwell time, and T_{setup} is the connection setup time. This captures the impact of connection duration on the total transferable volume.

To admit a link for a data flow, two simultaneous conditions must hold:

$$D_i \geq S^{(c)} \quad \text{and} \quad r_i \geq r_{\text{req}}^{(c)} \tag{9}$$

ensuring both sufficient capacity and rate for the targeted flow.

3.4.2 Delay Model. Communication latency is a critical performance metric in vehicular networks, particularly in V2V, V2I, and MEC-based edge systems that require the rapid and reliable exchange of safety messages [39, 40]. In classical network models, the overall end-to-end delay is generally decomposed into four core components: processing, queuing, transmission, and propagation [41]. To maintain a tractable delay analysis for the V2I scenario in this study, we assume a moderate network load. Under this condition, propagation delay becomes negligible due to the short communication distances, while queuing delay remains limited in the absence of severe congestion. Consequently, the total delay is approximated by the two dominant components: transmission and processing delays. It should be noted, however, that this approximation may lose accuracy under highly congested traffic conditions, where queuing effects can no longer be ignored

According to classical network delay models, the transmission delay is defined as the ratio between the transmitted data size and the achievable transmission rate [41]:

$$T_{\text{tx},i}^{(c)} = \frac{S^{(c)}}{r_{i,\text{nom}}} \tag{10}$$

The processing delay is modeled based on the available computational capacity of the RSU edge node, similar to common MEC computation models [42, 43]. This modeling approach is consistent with typical vehicular edge computing architectures where RSUs provide computation capabilities to nearby vehicles [44].

$$T_{\text{proc},i}^{(c)} = \frac{S^{(c)}}{C_i} \tag{11}$$

Following conventional communication delay decomposition models [41], the total delay is expressed as:

$$T_{\text{delay},i}^{(c)} = T_{\text{tx},i}^{(c)} + T_{\text{proc},i}^{(c)} = \frac{S^{(c)}}{r_{i,\text{nom}}} + \frac{S^{(c)}}{C_i} \tag{12}$$

Different types of data streams (control, voice, text, and multimedia) have different latency requirements. Accordingly, a maximum tolerable latency $L_{\text{req}}^{(c)}$ is defined for each data class based on representative QoS requirements reported for V2X services. In general, safety- and control-oriented traffic is subject to more stringent latency constraints than multimedia traffic, which can tolerate larger delays [30]. Therefore, an RSU is considered acceptable from a latency perspective only if

$$T_{\text{delay},i}^{(c)} \leq L_{\text{req}}^{(c)} \tag{13}$$

This criterion, together with the parameters related to the expected data volume during the dwell time and the achievable link capacity, forms the basis for decision-making in selecting the optimal RSU to support the desired data flow.

3.5 Multi-Criteria RSU Selection

3.5.1 Feasibility Constraints. Consider a vehicle that intends to transmit a data flow of class $\boldsymbol{c}$. For each candidate RSU $\boldsymbol{i}$, the dwell time $\boldsymbol{T}_{\text{dwell},\boldsymbol{i}}$, link rate $\boldsymbol{r_i}$, processing capacity $\boldsymbol{C_i}$, and class-dependent parameters $(\boldsymbol{S^{(c)}}, \boldsymbol{r}_{\text{req}}^{(\boldsymbol{c})}, \boldsymbol{L}_{\text{req}}^{(\boldsymbol{c})})$ are assumed to be available. The transmission delay, processing delay, and total delay follow the definitions previously given in (10)–(11)–(12). The dwell-based transferable capacity is evaluated using (8).

A strict feasibility filter ensures that an RSU can physically accommodate the required data size:

$$\mathcal{I}_0^{(c)} = \left\{ i \in \mathcal{I} \mid D_i \geq S^{(c)} \text{ and } T_{\text{dwell},i} \geq T_{\text{handover}}^{(c)} \right\} \tag{14}$$

If $\mathcal{I}_0^{(c)} = \varnothing$, no usable coverage is available and the algorithm terminates.

Next, the minimum rate and maximum delay constraints for class c are applied:

$$\mathcal{I}_1^{(c)} = \left\{ i \in \mathcal{I}_0^{(c)} \mid r_i \geq r_{\text{req}}^{(c)} \text{ and } T_{\text{delay},i}^{(c)} \leq L_{\text{req}}^{(c)} \right\}. \tag{15}$$

To select the most suitable RSU while maintaining service continuity under unfavorable channel conditions, a candidate set $\mathcal{C}^{(c)}$ is constructed using a QoS fallback mechanism:

$$\mathcal{C}^{(c)} = \begin{cases} \mathcal{I}_1^{(c)}, & \text{if } \mathcal{I}_1^{(c)} \neq \emptyset, \\ \mathcal{I}_0^{(c)}, & \text{if } \mathcal{I}_1^{(c)} = \emptyset \text{ and } \mathcal{I}_0^{(c)} \neq \emptyset, \\ \emptyset, & \text{otherwise.} \end{cases} \tag{16}$$

Here, if at least one RSU satisfies the strict QoS constraints, $\mathcal{C}^{(c)}$ is populated by $\mathcal{I}_1^{(c)}$. Otherwise, the algorithm falls back to the physically feasible set $\mathcal{I}_0^{(c)}$ to prioritize connectivity, or returns $\emptyset$ if no viable RSU exists.

3.5.2 Metric Normalization. Three metrics are considered for ranking: (1) total delay $\boldsymbol{T}_{\text{delay},\boldsymbol{i}}^{(\boldsymbol{c})}$, (2) link rate $\boldsymbol{r_i}$, (3) dwell-based transferable capacity $\boldsymbol{D_i}$. These metrics are normalized over the candidate set $\boldsymbol{\mathcal{C}^{(c)}}$, which contains the RSUs considered for ranking after the feasibility filtering stage. Typically, $\boldsymbol{\mathcal{C}^{(c)} = \mathcal{I}_1^{(c)}}$. If no RSU satisfies all QoS constraints simultaneously, the candidate set is expanded to include all RSUs in $\boldsymbol{\mathcal{I}_0^{(c)}}$ for score-based evaluation.

These three metrics jointly describe the key performance dimensions that shape vehicular edge connectivity. The delay component captures how sensitive the flow is to latency, the link rate provides a snapshot of the instantaneous wireless quality, and the dwell-based transferable capacity reflects whether the ongoing mobility pattern realistically allows completing the transmission. Evaluating these aspects together prevents the selector from focusing on a single dimension and helps maintain a balance between mobility effects, radio-link behavior, and application QoS requirements. To combine heterogeneous metrics within a unified decision framework, min–max normalization is applied following standard MCDM techniques [45, 46]:

:

$$\tilde{T}_i^{(c)} = \frac{T_{\text{delay},i}^{(c)} - \min_{j \in \mathcal{C}^{(c)}} T_{\text{delay},j}^{(c)}}{\max_{j \in \mathcal{C}^{(c)}} T_{\text{delay},j}^{(c)} - \min_{j \in \mathcal{C}^{(c)}} T_{\text{delay},j}^{(c)} + \varepsilon} \tag{17}$$

For metrics in which larger values indicate better performance, the normalization direction is inverted. The same normalization strategy is applied to the transferable-data metric so that lower normalized values consistently indicate better performance across all ranking criteria.

$$\tilde{r}_i = \frac{\max_{j \in \mathcal{C}^{(c)}} r_j - r_i}{\max_{j \in \mathcal{C}^{(c)}} r_j - \min_{j \in \mathcal{C}^{(c)}} r_j + \varepsilon} \tag{18}$$

$$\widetilde{D}_i = \frac{\max_{j \in \mathcal{C}^{(c)}} D_j - D_i}{\max_{j \in \mathcal{C}^{(c)}} D_j - \min_{j \in \mathcal{C}^{(c)}} D_j + \varepsilon} \tag{19}$$

3.5.3 Weighted Utility Function. A weighted-sum utility function, widely used in multi-criteria decision-making (MCDM) methods [45, 46], is then computed as

$$\text{Score}_i^{(c)} = w_T^{(c)} \tilde{T}_i^{(c)} + w_R^{(c)} \tilde{r}_i + w_D^{(c)} \widetilde{D}_i \tag{20}$$

where the weights satisfy

$$w_T^{(c)} + w_R^{(c)} + w_D^{(c)} = 1. \quad (21)$$

In the scoring function, r_i denotes the effective link rate observed at the application layer, which reflects the practical communication quality rather than the nominal PHY-layer rate.

The best candidate RSU is first identified as the one that achieves the minimum utility score within the candidate set:

$$i^* = \arg\min_{i \in \mathcal{C}^{(c)}} \text{Score}_i^{(c)} \quad (22)$$

To prevent unnecessary and frequent handovers (ping-pong effect) when a vehicle is already associated with an active RSU $i_{\text{cur}} \in \mathcal{C}^{(c)}$, a handover to the target RSU i^* is triggered only if the score improvement satisfies the hysteresis margin $H^{(c)}$:

$$\text{Score}_{i_{\text{cur}}}^{(c)} - \text{Score}_{i^*}^{(c)} \geq \text{H}^{(c)} \quad (23)$$

If $i_{\text{cur}} \notin \mathcal{C}^{(c)}$, its score is not available because scores are computed only for members of $\mathcal{C}^{(c)}$. Therefore, hysteresis is not applied and the vehicle directly selects i^*. If $i_{\text{cur}} \in \mathcal{C}^{(c)}$, a handover is performed only when the score improvement reaches the hysteresis margin $H^{(c)}$. If $i_{\text{cur}} = \text{NULL}$, the vehicle directly associates with i^*.

3.6 Algorithm Summary

Algorithm (1) summarizes the resulting multi-criteria RSU selection procedure with fallback stages and hysteresis.

Algorithm 1: QoS-Aware Multi-Criteria RSU Selection

1. **Input:** Candidate RSU set $\mathcal{I}$; service class c; required data size $S^{(c)}$; minimum required rate $r_{\text{req}}^{(c)}$; maximum tolerable latency $L_{\text{req}}^{(c)}$; connection setup time T_{setup}; handover dwell-time requirement $T_{\text{handover}}^{(c)}$; weights $w_T^{(c)}, w_R^{(c)}, w_D^{(c)}$; hysteresis margin $H^{(c)}$; current RSU i_{cur}.
2. **Output:** Selected RSU i_{sel}.
3. **Step 1**: Dwell-time prediction
4. For each $i \in \mathcal{I}$, compute the predicted dwell time $T_{\text{dwell},i}$using the relative-motion model in (1)–(7).
5. **Step 2:** Transferable data estimation
6. For each $i \in \mathcal{I}$, calculate the maximum transferable data during the predicted contact:
7. $D_i \leftarrow r_{i,\text{nom}} \max\left(0, T_{\text{dwell},i} - T_{\text{setup}}\right)$.
8. Here, $r_{i,\text{nom}}$ is expressed in Mbps, and D_i is expressed in Mb.
9. **Step 3**: Physical feasibility filtering
10. Construct the set of RSUs that satisfy the transferable-data and minimum-dwell-time requirements:
11. $\mathcal{I}_0^{(c)} \leftarrow \{i \in \mathcal{I} \mid D_i \geq S^{(c)} \wedge T_{\text{dwell},i} \geq T_{\text{handover}}^{(c)}\}$
12. If $\mathcal{I}_0^{(c)} = \emptyset$,
13. return **no feasible RSU** and terminate.
14. **Step 4**: QoS feasibility filtering and fallback
15. Construct the strict QoS-feasible candidate set:
16. $\mathcal{I}_1^{(c)} \leftarrow \left\{i \in \mathcal{I}_0^{(c)} \mid r_i \geq r_{\text{req}}^{(c)} \ \wedge \ T_{\text{delay},i}^{(c)} \leq L_{\text{req}}^{(c)}\right\}$
17. Define the candidate set $\mathcal{C}^{(c)}$:
18. **if** $\mathcal{I}_1^{(c)} \neq \emptyset$ **then**
    $\mathcal{C}^{(c)} \leftarrow \mathcal{I}_1^{(c)}$
19. **Else**
    $\mathcal{C}^{(c)} \leftarrow \mathcal{I}_0^{(c)}$
20. **Step 5**: Metric normalization
21. Normalize $T_{\text{delay},i}^{(c)}, r_i$,and $D_i$for all $i \in \mathcal{C}^{(c)}$according to (17)–(19).
22. **Step 6**: Utility score computation
23. For each i $\in \mathcal{C}^{(c)}$ compute
24. $\text{Score}_i^{(c)} = w_T^{(c)} \tilde{T}_i^{(c)} + w_R^{(c)} \tilde{r}_i + w_D^{(c)} \tilde{D}_i$
25. **Step 7**: RSU selection
26. $i^* = \arg\min_{i \in \mathcal{C}^{(c)}} \text{Score}_i^{(c)}$
27. **Step 8:** Hysteresis control
28. if i_{cur} = NULL then
    $i_{\text{sel}} \leftarrow i^*$
29. else if $i_{\text{cur}} \notin \mathcal{C}^{(c)}$ then
    $i_{\text{sel}} \leftarrow i^*$
30. Elseif $\text{Score}_{i_{\text{cur}}}^{(c)} - \text{Score}_{i^*}^{(c)} \geq \text{H}^{(c)}$ then

$i_{\text{sel}} \leftarrow i^*$

31. else
    $i_{\text{sel}} \leftarrow i_{\text{cur}}$
32. **Step 9:** Return the selected RSU
33. return i_{sel}

4 Results

In this section, simulation results are presented to evaluate the performance of the proposed multi-criteria RSU selection algorithm and these results are analyzed. The main objective of this evaluation is to measure the effectiveness of the algorithm in enhancing the stability of vehicle-to-infrastructure (V2I) communications in dynamic and high-mobility environments. The performance of the proposed method is compared with several baseline communication strategies, allowing for a clear assessment of its impact on key network performance indicators.

This evaluation is performed using a set of metrics including network throughput, end-to-end delay, dwell time, total data delivered, and the number of handovers. Together, these metrics provide a comprehensive view of the communication quality, connection stability, and data delivery efficiency in the studied scenario.

The rest of this section is organized as follows. First, the simulation environment and parameter settings are introduced. Then, the performance of the proposed algorithm is examined in comparison with the baseline strategies through time-series analysis, statistical distribution evaluation, and connectivity-level performance measures. The advantages and disadvantages associated with each approach are also outlined.

4.1 Simulation Environment

The proposed RSU selection algorithm was assessed with the aid of the SUMO traffic simulator. The simulation process was carried out in the ns-3 network simulator. This setup made it possible to represent vehicle mobility with good accuracy while also providing real-time access to communication-related parameters.

To evaluate the algorithm under realistic urban conditions, a Manhattan-grid urban scenario was considered. Vehicles were dynamically generated and traveled at uniformly distributed speeds while following standard lane movement rules. In this network, both fixed and mobile RSUs were deployed, each with a limited communication range and a specified processing capacity.

During movement, vehicles periodically evaluated the available RSUs and established a connection according to the RSU selection strategy. The main simulation parameters are summarized in Table 3.

Table 3. Simulation Parameters

Parameter	Value / Description
Simulation platform	SUMO with ns-3
Road topology	Manhattan urban grid ($1000\ \text{m} \times 1000\ \text{m}$)
Mobility model	Manhattan mobility model (lane-based, segment-wise constant speed)
Number of vehicles	200
RSU types	Fixed and Mobile RSUs
Communication model	V2I (vehicle-to-RSU)
Evaluation metrics	Dwell time, throughput, delay

4.2 RSU Selection Configuration

In heterogeneous vehicular networks, different classes of data flows impose distinct quality-of-service (QoS) requirements. Therefore, the proposed RSU selection algorithm adapts the weighting coefficients of the multi-criteria scoring function according to the traffic class. Although the proposed method is designed to support multiple traffic classes, the simulation results reported in this section focus only on multimedia traffic. This class was selected as a representative delay-tolerant service category to evaluate the QoS-aware behavior of the proposed RSU selection mechanism under high-throughput communication demands. The three metrics considered in the scoring function are:

- T_{delay} : total communication delay, including transmission and processing.
- r_{eff} : effective data rate of the RSU during the expected dwell time.
- D_{dwell}: transferable data volume during the vehicle's dwell time within the RSU coverage.

The relative importance of each metric varies depending on the type of data transmitted. For instance, safety and control messages are extremely delay-sensitive, whereas multimedia flows (e.g., video/AR) prioritize higher throughput and longer connection duration. To reflect these priorities, the weighting coefficients presented in Table 4 are adopted:

Table 4. Weighting coefficients for different traffic classes

Data class	w_T (delay)	w_R (rate)	w_D (dwell/data)
Safety / Control	0.5	0.2	0.3
Voice	0.4	0.3	0.3
Text / Non-safety	0.2	0.2	0.6
Multimedia (Video/AR)	0.2	0.4	0.4

The weights were selected based on relative QoS priorities defined in the 3GPP and ETSI standards [49] and were further validated through sensitivity analysis. This configuration ensures that the RSU selection mechanism prioritizes low-latency links for delay-critical flows while maximizing throughput and maintaining connection stability for high-bandwidth services.

The multi-criteria score for candidate RSU i and traffic class c is thus calculated as

$$\text{Score}_i^{(c)} = w_T^{(c)} \tilde{T}_i^{(c)} + w_R^{(c)} \tilde{r}_i + w_D^{(c)} \tilde{D}_i,$$

where $\tilde{T}_i^{(c)}$, $\tilde{r}_i$, and $\tilde{D}_i$ are the normalized metrics as described in Section 3.4.

4.3 Baselines

To evaluate the effectiveness of the proposed association strategy, we compare it with three representative baseline schemes widely used in vehicular networking and edge-assisted V2X systems. These baselines reflect three common association philosophies in the literature: geometry-based selection, mobility-stability-based selection, and multi-metric heuristic selection.

4.3.1 Nearest RSU (Distance-Based). The first baseline follows a simple geometric association rule in which a vehicle connects to the RSU with the minimum Euclidean distance. Distance-based or nearest-infrastructure association is commonly adopted in wireless network analysis due to its simplicity and its direct relation to wireless signal propagation characteristics [50]. In vehicular networks, RSU-based V2I/V2X communication models are widely discussed in the literature [51]. However, this baseline does not explicitly consider mobility dynamics or connection stability, which may lead to frequent handovers in high-mobility environments.

4.3.2 Maximum Stay-Time (STAYTIME). The second baseline adopts a mobility-aware association strategy that selects the RSU expected to provide the longest dwell time for the vehicle. The dwell time represents the estimated duration during which a vehicle remains within the coverage region of a candidate RSU. By prioritizing RSUs with longer predicted dwell times, this approach aims to reduce handover frequency and improve connection stability. Mobility-aware association and dwell-time-based decision mechanisms have been widely investigated in vehicular edge computing and V2X communication systems [52, 53].

4.3.3 Rate–Dwell (RD) Heuristic. The third baseline represents a lightweight multi-metric association heuristic that jointly considers the achievable data rate and the predicted dwell time of a vehicle within the coverage of a candidate RSU. Each RSU is assigned a score based on a normalized combination of these two factors, with equal weights (0.5, 0.5) used to maintain neutrality and interpretability**.**

The specific rate–dwell formulation used in this study is not taken directly from a single prior work. Instead, it is inspired by a broader group of mobility-aware and quality-aware association strategies that have been explored in vehicular networking and edge computing. Previous studies have shown that combining instantaneous link-quality indicators, such as rate or SINR, with mobility-related metrics like dwell time or trajectory stability can produce more reliable association decisions than approaches that rely only on distance or a single metric [53, 54]. Based on this idea, the RD heuristic is employed here as a representative multi-criteria baseline that reflects both communication capability and mobility stability during the association process.

4.3.4 Overview of the Proposed RSU Association Strategy. For completeness, we briefly summarize the main idea behind the proposed RSU association strategy before presenting the numerical results. Unlike conventional approaches that primarily prioritize the instantaneous link condition, the proposed method aims to maintain a more reliable and longer-lasting V2I connection in a heterogeneous vehicular environment.

To this end, the algorithm evaluates each candidate RSU from three complementary perspectives. First, it considers the expected communication delay, which reflects how quickly the requested data can be transmitted and processed. Second, it examines the effective link rate in order to capture the actual communication capability of the RSU. Third, it estimates how much data can realistically be delivered during the predicted dwell time,

i.e., the period for which the vehicle is expected to remain within the RSU coverage area.

Based on these factors, the selection process first eliminates RSUs that are not able to support the required transmission under the current mobility and QoS conditions. The remaining candidates are then compared using a weighted decision score that jointly accounts for delay, link quality, and dwell-time-based transmission opportunity. In addition, a hysteresis rule is applied to avoid unnecessary handovers caused by short-term fluctuations, which is particularly important in highly dynamic vehicular scenarios.

As a result, the proposed strategy is designed not only to improve communication performance, but also to preserve connection continuity and reduce avoidable association changes. This makes it particularly suitable for heterogeneous ITS environments, where stable and sustainable connectivity is often more valuable than simply pursuing the highest instantaneous rate.

4.4 Quantitative Results

This section presents a quantitative evaluation of the proposed multi-criteria RSU selection algorithm in comparison with three baseline strategies: Nearest RSU, STAYTIME, and the Rate–Dwell (RD) heuristic. To provide an in-depth assessment of the resulting performance trade-offs, the analysis is organized into three complementary dimensions: (i) dynamic time-series behavior and handover stability (Section 4.4.1), (ii) statistical distributions of network performance metrics using cumulative distribution functions (Section 4.4.2), and (iii) connection-level efficiency, including the amount of data transferred per connection and the handover rate (Section 4.4.3). Together, these analyses show how the proposed scheme trades instantaneous communication performance for longer and more stable V2I connections in dynamic vehicular environments.

4.4.1 Time-Series Performance and Stability Analysis.

In this subsection, we analyze the dynamic behavior of the proposed association strategy and compare it with the baseline schemes. The analysis includes throughput, end-to-end delay, dwell time, and cumulative transmitted data throughout the simulation period. In addition, the total number of handovers is examined to evaluate the signaling stability of each approach.

Fig. 3 illustrates the instantaneous throughput over time. The Nearest-RSU strategy often attains higher peak throughput by associating with geographically closer RSUs, which may offer favorable instantaneous link conditions. The RD strategy can also reach high peak throughput when RSUs with high achievable rates receive competitive scores despite its dwell-time-aware selection mechanism. In contrast, the proposed method maintains a relatively steady throughput of approximately 8 Mbps. Although this value is lower than that of the greedy approaches, the proposed scheme prioritizes link reliability and handover minimization, thereby avoiding frequent throughput drops typically caused by repeated handovers in high-mobility V2I environments.

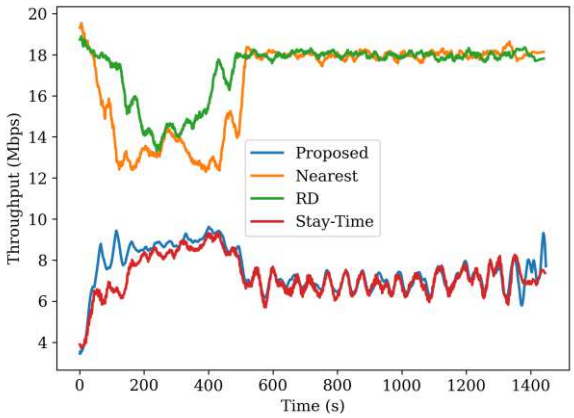


Fig. 3 Instantaneous throughput performance over the simulation duration

The variations in end-to-end delay are presented in Fig. 4. Consistent with the throughput results, the proposed strategy and the Stay-Time approach exhibit higher delay values (approximately 3–5 s) compared with the RD and Nearest baselines. In the considered multimedia-oriented scenario, this increase in delay reflects a controlled trade-off for significantly reducing the handover frequency. Since frequent handovers in vehicular networks may cause session interruptions and additional signaling overhead, the proposed method favors a more stable communication path to preserve session continuity, even at the cost of higher delay.

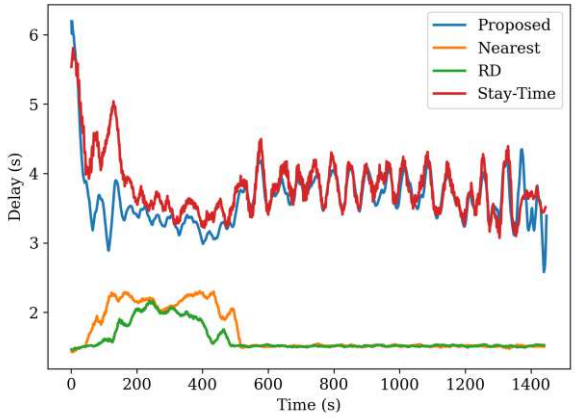


Fig. 4 End-to-end communication delay over time

Fig. 5 shows the dwell time of vehicle–RSU associations throughout the simulation. The proposed algorithm demonstrates longer and more stable connections during the initial stage of the simulation, followed by a relatively stable dwell-time trend in the later phase. This behavior indicates that the algorithm successfully mitigates the *ping-pong* effect by avoiding unnecessary RSU switching for marginal improvements in signal strength, thus preserving the current association as long as the connection quality remains within acceptable limits.

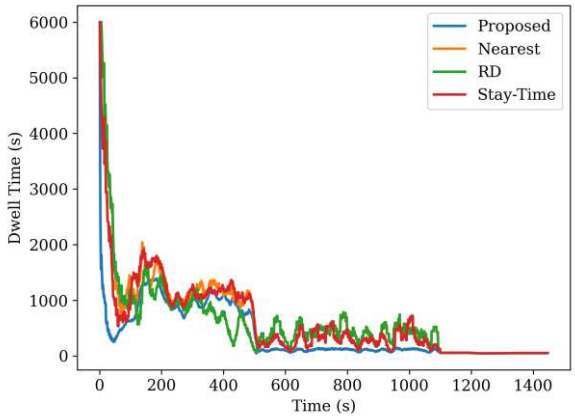


Fig. 5 Dwell time of vehicle–RSU associations over time

The cumulative data transfer is shown in Fig. 6. The RD and Nearest RSU strategies achieve a higher total volume (approximately 22,000 Mb and 21,000 Mb, respectively) over the simulation period. Our proposed scheme follows a nearly linear growth pattern and reaches about 11,000 Mb by the end of the simulation. Although this total volume is smaller, its smoother trend makes the data flow more predictable and stable. Such stability is especially useful for applications that require consistent Quality of Service (QoS).

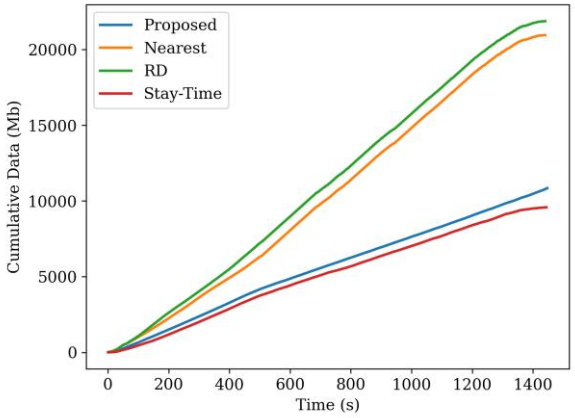


Fig. 6 Cumulative amount of transmitted data during the simulation

Finally, the most notable advantage of the proposed strategy is illustrated in Fig. 7, which presents the total number of handovers. While the Nearest, RD, and Stay-Time strategies experience extremely high handover counts (ranging from approximately 685 to 750 events), the proposed method reduces this number to fewer than 100. This corresponds to a reduction of more than 85% in the total number of handovers. By significantly minimizing handovers, the proposed algorithm reduces signaling overhead and lowers the risk of connection interruptions, making it well suited for stable V2I communication in high-mobility scenarios.

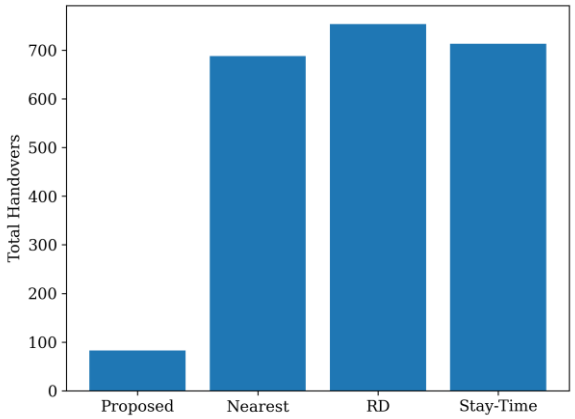


Fig. 7 Total number of handovers for different association strategies

4.4.2 Statistical Performance Distribution. Here we examine the cumulative distribution functions (CDFs) of throughput, end-to-end latency, and dwell time. These statistical distributions provide information about the reliability and stability of system performance.

The CDF of the network throughput is shown in Fig. 8. The Nearest and RD schemes show distributions with the majority of their performance in the range of 15–20 Mbps

and shifted towards higher throughput values. In contrast, the proposed algorithm shows a more conservative throughput distribution, mostly concentrated between 5–12 Mbps.

This performance gap is a deliberate outcome of the algorithm design. While the baseline schemes aggressively pursue the highest instantaneous signal strength to maximize data rate, they frequently associate with RSUs that the vehicle will quickly leave. The proposed scheme instead prioritizes connection longevity, which may require selecting a more distant or lower-capacity RSU that provides a more stable and persistent link.

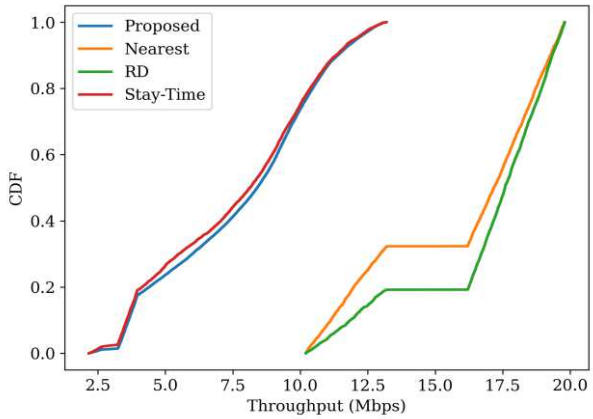


Fig. 8 CDF of throughput, illustrating the trade-off between peak data rate and connection strategy

Fig. 9 presents the CDF of end-to-end delay. In line with the throughput results, the proposed method exhibits higher latency than the RD and Nearest baselines, while remaining close to the Stay-Time scheme. The CDF indicates that about 80% of content blocks under the proposed scheme experience delays up to roughly 5.4 s, whereas RD and Nearest keep most transmissions below about 2.6 s.

From a network design perspective, this higher delay reflects a trade-off for improved connection continuity. In highly dynamic vehicular environments, a slightly higher but more predictable delay may be more manageable for application-layer protocols than the variability introduced by frequent handover interruptions in the Nearest and RD strategies.

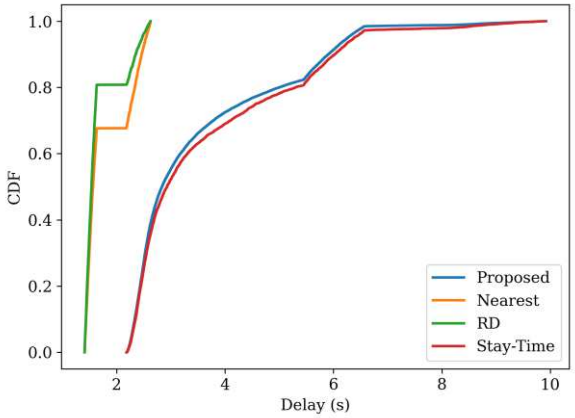


Fig. 9 CDF of end-to-end delay, showing the latency distribution for different association strategies

The primary advantage of the proposed algorithm is clearly demonstrated by the dwell-time CDF shown in Fig. 10. Dwell time is a key metric for evaluating handover efficiency and connection stability. The results indicate that for the RD and Nearest schemes, nearly 80% of all connections last less than 100 s, reflecting a highly unstable environment with frequent re-associations.

In contrast, the proposed algorithm significantly shifts the distribution toward longer connection durations, with a substantial fraction of associations persisting beyond 400–600 s. By effectively identifying long-term RSU candidates, the proposed scheme substantially reduces signaling overhead and provides a more stable foundation for V2X services, thereby justifying the trade-offs observed in throughput and delay.

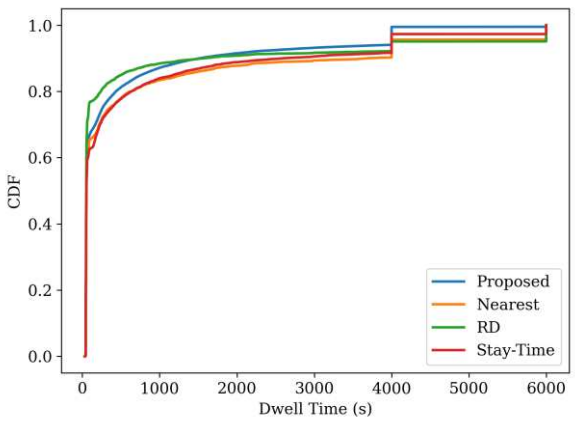


Fig. 10 CDF of dwell time, highlighting the superior connection longevity achieved by the proposed algorithm

4.4.3 Connection-Level Performance Analysis. Although instantaneous metrics such as throughput and delay provide valuable insights, they do not fully capture how efficiently connections are utilized in highly dynamic vehicular environments. In practice, the effectiveness of a

connection strategy is more accurately reflected by the amount of data delivered during each established session and by the frequency of connection switches. Accordingly, this subsection evaluates the connection-level efficiency of the considered algorithms using two key indicators: the average data transferred per connection and the handover rate.

The volume of data successfully transmitted during a single connection session is illustrated in Fig. 11. Our proposed algorithm transmits approximately four times more data per connection than the RD and Nearest schemes. Clearly, the performance of the proposed algorithm is better than that of the baseline schemes. According to these results, the proposed scheme remains stable for a sufficient time after the connection is established to enable significant data transmission. The RD and Nearest methods often connect to different access points to find stronger instantaneous signals, which causes fragmented communication sessions and limited data delivery per connection

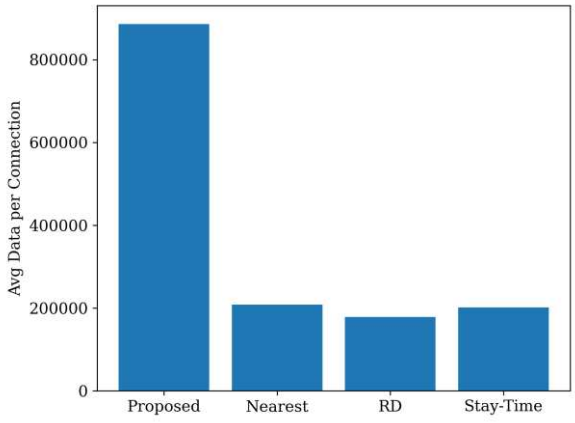


Fig. 11 Average data transferred per connection for different association strategies

The stability advantage of the proposed algorithm is further confirmed by the handover rate shown in Fig. 12. The results demonstrate that the proposed scheme substantially reduces the number of handovers compared with the alternative approaches. Whereas the Nearest and RD strategies exhibit frequent connection switching due to rapid variations in relative signal strength, the proposed method maintains a considerably lower handover rate.

Reducing unnecessary handovers is of great importance. Frequent connection changes cause signaling overhead, temporary packet loss, and additional processing load on both vehicles and infrastructure. In our proposed algorithm, connections are longer and more stable, which increases the utilization of network resources and also minimizes the operational overhead associated with repeated connection establishment procedures.

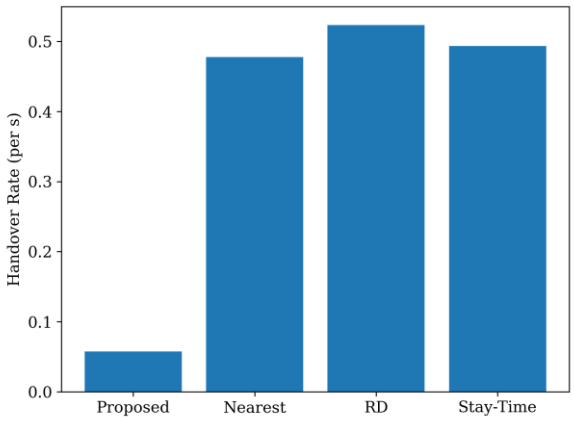


Fig. 12 Comparison of handover rates among different association strategies

Overall, the connection-level analysis underscores the practical advantage of the proposed scheme. Rather than aggressively switching between access points to maximize short-term signal quality, the algorithm prioritizes sustained and reliable connectivity, thereby enabling more efficient data delivery and significantly reducing network instability.

5 Conclusion

The research developed the dynamic RSU communication system with a multi-criteria evaluation function to maximize connectivity in HetVNETs. Contrary to conventional communication systems where a one-off criterion is used for the evaluation process, this system dynamically assigns the weightage of the criteria depending on the traffic category associated with the vehicles. Through balancing the sum of delay (T_{delay}), effective transmission rate (r_{eff}), and the amount of data to be delivered (D_{dwell}), the proposed method guarantees a robust selection system for the required services.

The simulation outcomes demonstrate that incorporating the parameters with mobility aware behavior significantly mitigates the effect of ping pong problem and achieves a remarkable decrease in the number of handovers. While the framework operates on a calculated trade-off between throughput and latency, the achieved improvement in continuity of connections offers a stronger base for vehicular fast communication. Future work will focus on integrating machine learning techniques to further enhance the prediction accuracy of vehicle trajectories and dwell times within dynamic and uncertain urban environments.

Statements and Declarations

Competing Interests: The authors declare that they have no competing financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

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