



Spectral Efficiency and Hybrid Multi-RSU Deployment with Cost Optimisation in Vehicular Ad Hoc Networks

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Abstract

Enhanced traffic management and safety can be achieved using decentralised networks such as Vehicular Ad Hoc Networks (VANETs), which allow communication amongst vehicles. These networks support dynamic, real-time communications; however, they face difficulties in terms of scalability, security and network stability. Improved vision efficiency, cost reduction and enhanced connectivity in VANETs can be realised using multi-RSU and clustering methods, revealing real-world benefits. This research seeks to improve communication efficiency in VANETs by addressing issues such as network delay, power usage and communication cost. The goal is to improve network reliability in a dynamic vehicular setup with fixed Roadside Units (RSUs), ensuring constant connectivity and reduced overhead. Spectral Efficiency and Hybrid Multi-RSU Deployment with Cost Optimisation (SEHMR) approach introduces an innovative solution for improving vehicular communication. The system integrates clustering, scheduling and continuous cluster maintenance of vehicles. By analysing the initial population and probability values of vehicles, the Cost Optimisation (DEA) algorithm effectively optimises costs. RSUs are strategically positioned to improve coverage, communication and power efficiency. This approach is evaluated through extensive simulations using NS2 and the SUMO mobility suite, measuring performance through metrics such as efficiency, throughput, packet delivery ratio, data loss, end-to-end delay and overhead. The proposed SEHMR-VANET is compared with basic approaches such as HGAR-VANETS, ROOP-VANET and ISFF-VANETS. Results indicate that SEHMR-VANET achieves higher energy efficiency and lower delay and data loss, revealing its effectiveness in improving traffic communication.

Keywords: Vehicular ad-hoc networks (VANETs); RSU deployment; Cost optimisation; Clustering; DEA algorithm

1. Introduction

Vehicular Ad Hoc Networks (VANETs) are increasingly important in the modern era, demonstrating numerous applications in smart environments [1],[2]. Currently, due to the highly increased number of vehicles in real-time traffic, network safety and traffic control have become crucial, supporting manufacturers in the

advancement of future accomplishments of Intelligent Transportation Systems (ITS) [3],[4]. Two wireless data transmission standards, DSRC and WAVE, enable effective vehicle communication. Despite their capability to provide secure information for vehicle-to-vehicle (V2V) communications, they may consume excessive bandwidth due to its limited capacity, especially with changing traffic conditions. This limitation

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affects the timely delivery of important messages [5],[6]. The bandwidth and frequency range allocated for DSRC by the Federal Communications Commission are 75 MHz and 5855.925 GHz, respectively. IEEE 802.11 is used as the local area network standard for vehicular data transmission. In earlier VANET-based research, DSRC was utilised for wireless communication [7]. WAVE was recently introduced, with IEEE802.11p and IEEE 1609 serving as its supporting routing standards. Other technologies that support this routing standard include Wi-Fi, LTE-V, Bluetooth and 5G, and the structure of vehicular communication is illustrated in Figure 1. In high-altitude environments, including those dominated by trucks and buildings, the primary challenge lies in ensuring the quick transmission of warning signals to prevent accidents. Instead of employing range-based techniques, communication reliability can be improved using meta-heuristic methods to identify NLOS nodes, regardless of the obstacles encountered [8].

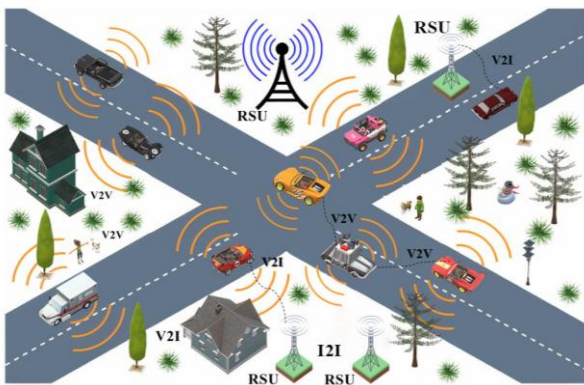


Fig. 1. Structure of Vehicular Communication

In recent years, vehicle mobility in VANETs has become highly unpredictable, contributing to delays in vehicle communication and affecting the performance of V2V data transmission and vehicle-to-infrastructure-based communication. Different types of resources, traffic conditions and QoS requirements are observed in various VANETs, including traditional and M2M connections. In contrast, earlier architectures, such as 4G and LTE-A, rely on fixed resource allocation systems, limiting their adaptation to changing traffic conditions and dynamic environments [9]. Aiming to achieve effective performance, route selection for data transmission between the sending vehicle and the receiving vehicles needs to be optimised. Other elements, such as vehicles and RSU, are highly concentrated, increasing the possibility of reducing

delay and improving vehicle throughput. Critical parameters include high communication reliability and optimal route selection. DSRC, which is based on IEEE802.11, addresses overhead and high latency in high-speed VANETs due to rapid changes in network topology. Although WAVE, which uses IEEE 802.11p and IEEE 1609, was introduced to improve compatibility, the 75 MHz bandwidth allocated to DSRC is insufficient to satisfy the heavy data requirements of VANETs [10].

Effective vehicle communication is possible only through a routing protocol, making intelligent cluster formation a crucial component. Additionally, proper localisation of vehicles and RSUs helps in effectively controlling congestion. Despite supporting high data rates and providing reliable V2V communication, the overhead of traditional DSRC-based VANETs reduces their reliability, whilst LTE does not offer V2C communication. However, using LTE for D2D communication can minimise transmission paths and delays, thereby improving VANET efficiency [11],[12]. Earlier research has identified certain flaws in the clustering process that must be addressed, including channel contention value, traffic congestion ratings and packet loss. These factors are connected to the cluster size, requiring careful consideration. Large clusters tend to connect numerous high-speed vehicles simultaneously, frequently increasing traffic load and delay. Conversely, small clusters increase cluster counts, leading to an increase in power utility and insufficient resource allocation. Therefore, an effective method is essential to achieve a balanced cluster size amongst vehicles. In VANET protocols, security messages (SM) are sent over the control channel, whilst non-secure data (SD) are prioritised for routing. Meanwhile, TDMA-based cluster MAC protocols suffer from high latency and low throughput due to slot problems and inefficient resource usage [13]. Aiming to address these challenges, this paper introduces the SEHMR-VANETs approach, and its key contributions are outlined.

1.1. Research Contributions

Aiming to achieve effective vehicular communication, this research focuses on spectral efficiency and hybrid multi-RSU deployment with cost optimisation. Firstly, a model system is developed for cluster formation, cluster maintenance and a scheduled time model, encompassing vehicles, clusters and a base station. Secondly, cost optimisation is performed using the DEA algorithm and its probability analysis.

Optimal RSU selection prioritises cost-effective and strategically placed RSUs. This selection process is mainly used to reduce delays between vehicle- and infrastructure-based communication. The simulation assesses SEHMR efficiency compared to baseline approaches for selected vehicles through the analysis of various parameters.

An RSU-based DEA algorithm was developed to optimise costs in VANET mobility. This algorithm introduced a selection strategy based on network load factors, cost capacity and scheduling. A mathematical model was used for performance evaluation, along with a ranking system that prioritised workload and delayed metrics to enhance communication efficiency.

The organisation of the paper is as follows. Section 2 analyses the earlier work related to clustering and vehicle location to identify their drawbacks. Section 3 constructs the cluster-based vehicular system. Section 4 elaborates the proposed SEHMR-VANET approach with the cost optimisation method and effective RSU deployment process. Section 5 performs simulation experimentations, effectively collecting the outputs of the proposed work and comparing them with the earlier methods, such as HGAR-VANETS, ROOP-VANETS and ISFF-VANETS. Section 6 concludes the paper with its future scope and research.

2. Related Work

In [14], Forough Goudarzi et al. developed a VANET protocol based on geographical source routing. Additionally, an ant-based method is used to determine the best path for maintaining strong network connectivity. This method reduces end-to-end latency and routing control overhead, despite providing only minimal network coverage. In [15], a mobile edge computing (MEC)-based communication platform for VANETs was established. Additionally, they introduced an effective charging information dissemination system based on the widely used multi-objective communication optimisation technique between MEC servers and transiting EVs. Whilst this system improves the packet delivery ratio (PDR) and reduces overhead costs, it has substantial energy consumption. In [16], HABEEB BELLO-SALAU et al. suggested two types of CSO models for efficient route identification in VANETs. Additionally, a genetic algorithm (GA) with an inverse mutation operator was applied to enhance exploration capabilities. Although this approach achieves effective routing, it introduces high complexity. In [17], Yuan-ai Xie et al. combined

clustering and RPC techniques to optimise SE and EE in VANETs. When the unified utility is non-convex and the probability requirements are intractable, the issue is converted into a tractable convex problem using Bernstein approximation and successive convex approximation. However, achieving successful routing requires substantial computational overhead.

In [18], FAN YANG et al. proposed an optimisation model to highlight the sensor deployment process, and a pre-deployment strategy is recommended to address the optimisation problem. This approach improves network overhead and network communication adaptability but requires substantial computational time. In [19], Hamza Ijaz et al. proposed the intelligent forwarding protocol. This highly effective and dependable multi-hop broadcasting protocol leverages efficient communication, ACK decoupling and an effective collision resolution mechanism in VANET. Despite the high energy cost, this protocol notably reduces message propagation time and increases PDR. In [20], SUOPING LI presented a four-node system, encompassing Non-OR, SOR-AP, SOR-V and DOR-APV, which accounts for relay communication connections and establishes several channel models for various kinds of communication. This technology successfully achieves throughput and energy efficiency, alleviating latency. In [21], Zhenguo Gao et al. developed a greedy3P4, a greedy approximate technique for addressing the one-dimensional roadside unit Deployment (DIRD) issue.

In [22], Zhenguo Gao et al. examined a novel approach that attempted to provide the best possible methods. Moreover, on the DynLim approach, OptDynLim is considered the best algorithm, thereby establishing its optimality. This algorithm solves the One-Dimensional RSU Deployment Problem; however, its process is highly complex. In [23], Floriano et al. created a concept for an Intelligent Transportation System (ITS) system that supports platooning management and aims to optimise groups globally. Additionally, the search for an optimal platoon is performed using a unique method based on grey wolf optimisation. This method determines the efficient size, speed and average energy consumption of a platoon but incurs high overhead costs. In [24], Sreya Ghosh et al. offered a unique routing method called Reduced Routing Overhead Using Ant Colony Optimisation (RRO-ACO) with ACK packet transmission to handle dynamic vehicular traffic with high mobility. However, this approach increases the vulnerability and unreliability of multi-hop communication

networks. In [25], Bhushan Yelure et al. proposed the PSOR routing protocol to determine the next forwarding vehicle based on vehicle speed and distance. Despite its considerable computational expense, this protocol yields throughput, overhead and message delivery ratio.

In [26], Khalilollah Raeisi et al. presented a non-cooperative method for packet forwarding in VANETs, which aim to reduce traffic congestion. This reduction ultimately minimises node payments to the network side and improves traffic flow; however, it only applies to local area networks. In [27], Zhuwei et al. focused on the concurrent optimisation of the control strategy and resource management of the CCC system in the presence of short communication delays, indicating an optimum control method. In [28], Joahannes et al. developed a combination-based task allocation mechanism that efficiently allocates tasks in vehicular applications. Energy consumption is reduced using this mechanism. In [29], Ajit Noonia et al. presented a handoff framework for enhancing communication in a hybrid vehicular network. The strategy has been effective in achieving inter- and intra-regional communication whilst considering handoff issues. Despite using a substantial amount of energy, the characteristics of the received packet, packet loss and communication delay are effectively collected. In [30] using RSU, Ezraa al et al. suggested the use of collaborative vehicle location management to locate the target vehicles. The RSUs should be positioned at road intersections, and the optimal number is equal to the number of crossings based on the PDR, packet loss ratio, overhead and end-to-end latency. However, a drawback of this strategy lies in complexity level.

In [31], a hybrid optimisation approach combining the Firefly algorithm and the GA is developed to achieve faster communication amongst vehicles. This method is moderately suitable for dense network scenarios but needs improvement in terms of delivery ratio and throughput. In [32], vehicle routing is improved through the creation of an optimisation-based routing model, reducing link failures between high-speed vehicles during data transmission from the sender node to the receiver node. In [33], intelligent optimal route selection is performed using the Firefly method. Therefore, the delivery ratio is increased, and the vehicle transmission delay is reduced each time. However, this approach is not suitable for a network with a large number of vehicles. Aiming to address the earlier drawbacks in this research article, the efficiency-based network model, cost optimisation and optimal RSU deployment are investigated. The upcoming

sections will elaborate on the details of the proposed SEHMR-VANETs.

The conventional techniques used for the comparison include HGAR [31], ROOP [32] and ISFF [33]. The major drawback of HGAR lies in its inability to attain maximum delivery ratio and throughput, as it deals with traditional optimisation algorithms such as the Firefly algorithm and the GA particularly for densely populated areas. This limitation leads to increased delay and packet loss during high-speed vehicle mobility. Meanwhile, the ROOP suffers from link failures during data transmission, resulting in increased data loss and delay, ultimately affecting the overall performance of the network in densely populated areas. In ISFF, the RSU localisation accuracy is moderate and requires further improvement. These identified drawbacks in earlier studies emphasise the need for enhancements to improve overall vehicular network performance. Aiming to address these issues, this article mainly concentrates on cluster-based optimisation, proper RSU positioning and cost optimisation to attain overall effective communication in a cost-effective manner.

3. Preliminaries

3.1. Cluster Model

The high mobility complicates communication, whilst clustering improves effectiveness through maintenance and organisation.

3.1.1. Initial Clustering Process

In the initial phase of the network, vehicles and a base station assign IDs, send Hello packets to identify neighbours and establish clusters through the cluster head selection based on mobility.

3.1.2. Cluster Maintenance Process

In high-speed networks, vehicles experience connectivity loss due to mobility. Data transmission is conducted in time slots, reallocating slots to nearby vehicles when one leaves the cluster. This process supports delay reduction and facilitates energy consumption. Vehicles moving out of a cluster seek the strongest available signal, whilst a new cluster head identifies potential new members.

3.2. System Model

The VANET system uses a hybrid architecture based on the IEEE 802.11p standard, organised into

four clusters on a two-lane road. Through a constant speed model, the system employs TDMA communication, facilitating the interaction between a cluster head (CH) and child nodes in defined time slots.

3.2.1. Scheduled Time Model

The base station assigns IDs to incoming vehicles, sending (Hello) packets to identify neighbours and create clusters. Vehicles adjust time slots for efficient switching, and a selected CH manages child vehicle status and information, adapting to new vehicles based on mobility within the network of four CHs.

Pseudo code for the CH selection process.

Input:

CH : Set of cluster heads
 V : Set of vehicles
 BS : Base station
 CA : Coverage area of cluster heads
 T : Number of iterations

Output:

Updated clusters and routing tables

Procedure Cluster Formation

```

for  $t \leftarrow 1$  to  $T$  do
  for each  $CHq \in CH$  do
    for each  $Vp \in V$  do
       $d \leftarrow \text{Distance}(CHq, Vp)$ 

      if  $d \leq CA_{CHq}$  then
        Assign  $Vp$  to  $CHq$ 
      else
        Remove  $Vp$  from  $CHq$ 
      end if

      Update routing table of  $CHq$ 
    end for
  end for
end for

```

End Procedure

4. Author Name(s) and Affiliation(s)

In SEHMR-VANETs, to expand VANET usage, the concept of cost optimisation and effective RSU deployment with a scheduling process is introduced. The workflow of the proposed SEHMR-VANETs is illustrated in Figure 2.

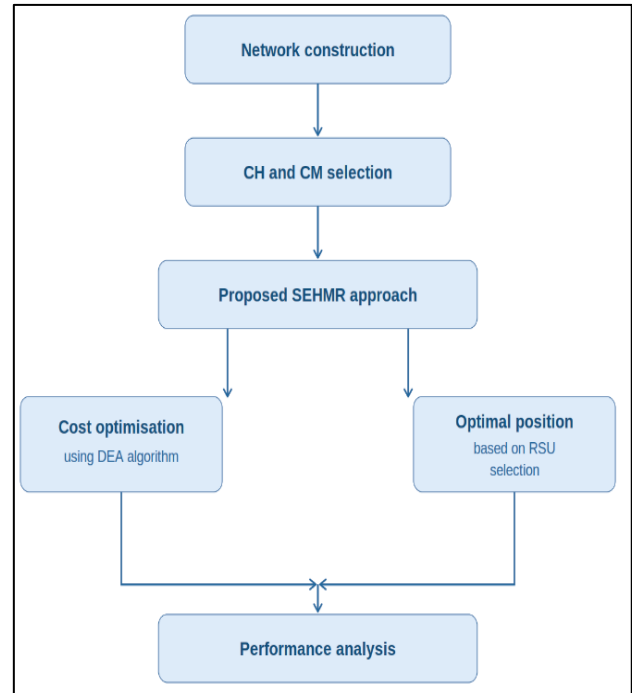


Fig. 2. Workflow of the Proposed SEHMR-VANETs

4.1. Cost Optimisation Process in VANETs

The DEA is employed to optimise costs in VANETs. This process begins with initialising a population and generating new individuals by evaluating the vector differences amongst existing ones. Individuals with higher fitness replace those with lower fitness, prompting continuous evolution. However, the DEA faces issues in VANETs due to failed individual updates and poorly organised parameters that can extend convergence times. Addressing these limitations, along with strategically deploying RSUs based on network load, can enhance communication efficiency [15], as expressed in Equation (1).

$$l_e^i = 1, (\sum_{t=1}^T C_s \leq \sum_{t=1}^T (\rho - 1)(\Phi_i(t_0))) \quad \dots(1)$$

where variables C_s and $\Phi_i(t_0)$ represent the costs of RSUs and effective RSUs, respectively, whilst ρ denotes a constant coefficient. A change in position is required if the BS costs are lower than the effective RSUs.

$$\begin{cases} l_b^i = 1, (DC_B + \rho_B^i \geq DC_E) \\ l_e^i = 1, (DC_B + \rho_B^i \geq DC_E) \end{cases} \quad \dots(2)$$

where the terms DC_B and DC_E refer to the base station and effective RSU deployment costs, respectively, optimising costs. The DEA algorithm

optimises solutions by initialising a population based on parameters such as size and scaling factor. The algorithm iteratively generates new individuals through mutation and crossover, ultimately refining the placement of effective RSUs in a vehicle communication network model.

The DEA algorithm, which is mainly selected to obtain proper RSU localisation, encompass the following steps: data collection, constant and variable selection, vehicle efficiency analysis and optimised node selection.

4.2. Optimal Position Selection for Effective RSU

4.2.1. Effective RSU Determination

This section introduces mathematical calculations for effective RSU selection based on their positions, accounting for deployment costs and initial delays to determine a weighted function [10], as expressed in Equation (3).

$$f = (c_1 \times DC_E) + (c_2 \times f_1) \quad \dots(3)$$

where,

$$f_1 = \min \sum_{i=1}^n D_i \quad \dots(4)$$

where (4) α and β are delay factors, with f_1 indicating communication delays between RSUs.

4.2.2. Weight-based Optimal RSU Selection

The parameters considered for the weight-based optimal RSU selection process include RSUs ($RSU = rsu_1, rsu_2, \dots, rsu_n$), workload of RSUs (WL_{rsu}), packet queue of RSU (Q_{pack}) and packet slack time (ST_{pack}). The weights of each parameter for ST_{pack} , Q_{pack} and WL_{rsu} are all assumed to be 33.33%, and the rank of RSU is measured [14] and expressed in Equation (5).

$$RSU_{ij} = \frac{RSU_{ij} - \min_j}{\max_j - \min_j} \quad \dots(5)$$

where the term RSU_{ij} represents a rank factor evaluated by specific criteria, including minimum (\min_j) and maximum (\max_j) values.

The weight ranking according to the normalisation table is calculated as follows:

$$\begin{aligned} rsu_1 &= (w_2 \times \alpha_1 + w_3 \times \beta_1 + w_1 \times \gamma_1) (0.33 \times \alpha_1 \\ &\quad + 0.33 \times \beta_1 \\ &\quad + 0.33 \times \gamma_1) rsu_2 (w_2 \times \alpha_2 \\ &\quad + w_3 \times \beta_2 + w_1 \times \gamma_2) \\ &= (0.33 \times \alpha_2 + 0.33 \times \beta_2 \\ &\quad + 0.33 \times \gamma_2) \end{aligned}$$

$$\begin{aligned} rsu_2 &= (w_2 \times \alpha_3 + w_3 \times \beta_3 + w_1 \times \gamma_3) \\ &= (0.33 \times \alpha_3 + 0.33 \times \beta_3 \\ &\quad + 0.33 \times \gamma_3) \end{aligned}$$

According to this calculation, the values of the normalisation parameters are obtained.

The calculations are then continued using these equations, and the rank calculations are determined as follows.

$$\begin{aligned} rsu_1 &= (0.33 \times \alpha_1 + 0.33 \times \beta_1 + 0.33 \times \gamma_1) = \\ &= (0.33 \times 0.8 + 0.33 \times 20 + 0.33 \times 80) \\ &= (0.264 + 6.60 + 26.4) = 33.264 \end{aligned}$$

$$\begin{aligned} rsu_2 &= (0.33 \times \alpha_2 + 0.33 \times \beta_2 + 0.33 \times \gamma_2) = \\ &= (0.33 \times 0.9 + 0.33 \times 40 + 0.33 \times 90) = \\ &= (0.297 + 13.2 + 29.7) = 43.197 \end{aligned}$$

$$\begin{aligned} rsu_3 &= (0.33 \times \alpha_3 + 0.33 \times \beta_3 + 0.33 \times \gamma_3) \\ &= (0.33 \times 1.0 + 0.33 \times 60 \\ &\quad + 0.33 \times 100) \\ &= (0.33 + 19.8 + 33) = 53.13 \end{aligned}$$

The system features three ranks of RSUs: rank 1 rsu_1 , rank 2 rsu_2 and rank 3 rsu_3 , optimising vehicular communication efficiency at each moment.

5. Results and Discussion (Simulation Environments)

The simulation of the proposed SEHMR-VANET approach is conducted using the NS2 network simulator. The main focus is on efficient RSU selection and performance enhancement in VANETS. For this purpose, NS2 with SUMO is also considerable suitable for implementation. The experiments are performed under two conditions: variations in vehicles and speeds (10–100 Km/h). The parameters involved in the performance analysis include energy efficiency, throughput, PDR, data loss ratio, end-to-end delay and overhead. For comparative analysis, the earlier studies, such as HGAR-VANETS [31], ROOP-VANETS [32] and ISFF-VANETS [33], are considered. The inputs used in the implementation are presented in Table 1, and the performance analysis values are shown in Table 2.

**Table 1,
Simulation settings**

Parameters	Values
Simulator	NS2.35
Run Time	100 ms
Network Coverage Area	500 m × 500 m
No of Vehicles	100 vehicles
Antenna Type	Omni-directional Antenna
Communication Technology	TDMA Technology
UMTS Threshold	-94 dBm
Queue Type	DropTail
Node Speed	10 Km/h to 50 Km/h
Initial Power	1000 mJ
Transmission Power	0.500 Joules
Receiving Power	0.050 Joules
Data Rate	250 Kbps
DATA Traffic	CBR
Agent Type	UDP

5.1. Performance Metrics

The parameters used in performance evaluation include energy efficiency, throughput, PDR, data loss ratio, end-to-end delay and overhead.

5.1.1. Energy Efficiency Analysis

Efficient network designs are achieved by minimising power consumption during data transfer operations. VANETs, which are resource-constrained, experience reduced energy consumption due to increased energy efficiency, resulting in optimised network performance and low energy costs in Equation (6).

$$EE = \frac{\text{Total Data Successfully Transmitted}}{\text{Total Energy Consumed}} \quad \dots(6)$$

5.1.2. Packet Loss Ratio Calculation

Data loss is mainly attributed to the simultaneous entrance of excess data in a particular queue. These drawbacks are resolved in the proposed work with the effective implementation of RSUs. Therefore, the number of data losses is reduced, as shown in Equation (7).

$$PLR = \left(\frac{\text{Number of Packets Lost}}{\text{Total Number of Packets Sent}} \right) \times 100 \quad \dots(7)$$

5.1.3. Throughput Calculation

This calculation involves the maximum data packets that are communicated from all nodes,

which include the forwarded packets. Throughput is the rate at which data is transmitted from a source through the network to the destination. This rate signifies the data handling capability of the network, as shown in Equation (8).

$$T = \frac{\text{Total Data (in bits) Successfully Received}}{\text{Total Time Taken (in seconds)}} \quad \dots(8)$$

5.1.4. Packet Delivery Ratio Calculation

This calculation focuses on the ratio of data packets effectively transmitted to the destination to those generated from the source. The PDR is expressed as the percentage of total packets sent by the source that are received in the destination. This ratio measures how effectively the network can guarantee the delivery of transmitted data to its target audience. A higher PDR results in a more reliable and efficient network, as shown in Equation (9).

$$PDR (\%) = \left(\frac{\text{Number of Packets Successfully Received}}{\text{Total Number of Packets Sent}} \right) \times 100 \quad \dots(9)$$

5.1.5. End-to-End Delay Calculation

End-to-end latency is the total time taken for a packet of data to travel across the entire network from source to destination. This calculation involves all delays, including processing times, transportation queues and more. End-to-end downstream data transfer is faster and more efficient, as shown in Equation (10).

$$D_{e2e} = N \times (D_{proc} + D_{queue} + D_{trans} + D_{prop}) \quad \dots(10)$$

5.1.6. Routing Overhead Calculation

Routing beyond the network boundaries involves additional information and computing resources necessary to maintain and control routing information. The calculation considers status messages and symbols that enable the creation, updating and revising of routes. Routing protocols are improved with reduced overhead, which, in turn, degrades the overall network performance, as shown in Equation (11).

$$\text{Routing Overhead (RO)} = \frac{\text{Total Number of Control Packets Transmitted}}{\text{Total Number of Data Packets Successfully Delivered}} \quad \dots(11)$$

5.2. Results and Discussion

As shown in Figure 3, the calculation of energy efficiency for the varying number of vehicles ranges from 10 to 100. When a certain amount of data is successfully transferred, the delivery to the destination is considered successful, regardless of whether it is measured in bits, bytes or packets. The overall energy consumption, typically expressed in Joules, is incurred during the data transfer. In Figure 3, compared to previous techniques, HGAR-VANETS, ROOP-VANETS and ISFF-VANETS achieve 198, 228 and 298 Joules, respectively. Conversely, the proposed model achieves a higher energy efficiency of 322 Joules. The proposed SEHMR-VANETS protocol demonstrates the highest energy efficiency amongst the four protocols.

Figure 4 shows the data loss performance for the varying number of vehicles, ranging from 10 to 100. In Figure 4, the total count of data packets sent by the source failed to reach their destination. The sum of transmitted packets represents the total number of data packets sent by the source. When the data loss ratio is compared with previous techniques, HGAR-VANETS, ROOP-VANETS and ISFF-VANETS achieve 26%, 19% and 11%, respectively. In contrast, the proposed SEHMR-VANET achieves a lower ratio of 9%. Overall, the proposed SEHMR-VANET protocol demonstrates the lowest data loss ratio amongst the four protocols.

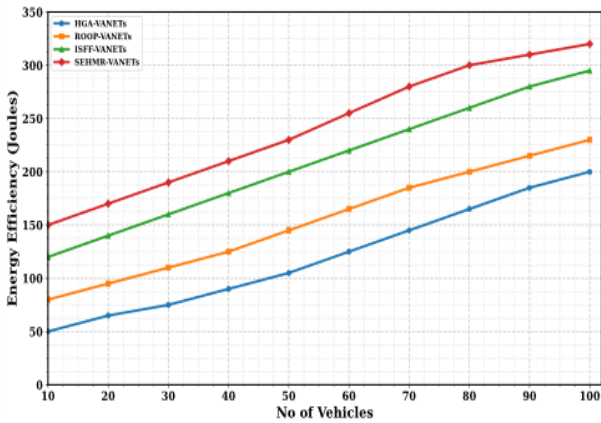


Fig. 3. Energy efficiency calculation

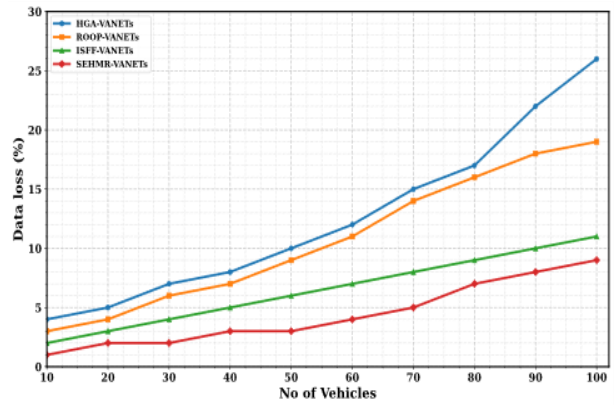


Fig. 4. Data loss calculation

Figure 5 illustrates the throughput of the baseline approaches, which are compared with the proposed SEHMR-VANETS for the varying number of vehicles, ranging from 10 to 100. The proposed approach focuses on improving the delivery rate and the throughput of the network, particularly cost optimisation, and increasing RSU placement. With reductions in data loss and delay, the vehicle queue line is properly maintained, providing a way to transmit the required information in the free queues. Units used to measure transmission include bits per second (bps), kbps, Mbps and Gbps, depending on the amount of data transferred. When throughput is compared with previous techniques, HGAR-VANETS is 250 Kbps, ROOP-VANETS is 265 Kbps and ISFF-VANETS is 315 Kbps. The proposed SEHMR-VANET has a higher throughput of 510 Kbps, demonstrating the highest throughput amongst the four protocols.

As shown in Figure 6, the number of packets delivered or received represent the total transmitted data. The sum of transmitted packets corresponds to the total number of data packets sent by the source. When comparing the PDR with previous techniques, HGAR-VANETS achieves 83%, ROOP-VANETS achieves 85% and ISFF-VANETS achieves 88.2%. Conversely, the proposed SEHMR-VANET achieves a PDR of 95%. Therefore, the SEHMR-VANET protocol demonstrates the highest PDR amongst the four protocols.

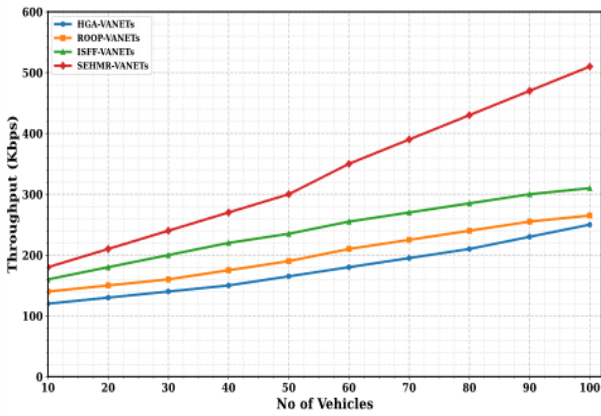


Fig. 5. Throughput calculation

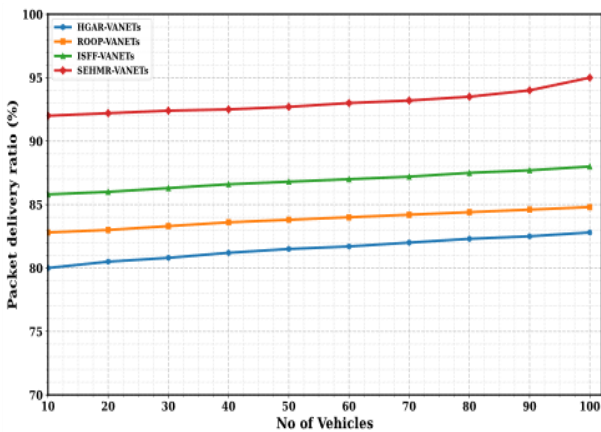


Fig. 6. Packet delivery ratio calculation

Figure 7 illustrates the end-to-end delay of the three baseline approaches, compared with the proposed SEHMR-VANETS for a varying number of vehicles ranging from 10 to 100. Through initial cluster-based communication, vehicle power consumption is normalised, and the subsequent effective RSU selection process expands the coverage area of the RSU, mitigating transmission delay between the sender vehicle and the receiver. Comparatively, the delay produced by the proposed SEHMR-VANETS is less than the baseline approaches, allowing direct data transmission between vehicles and the RSU in the required period.

N is the number of hops that a packet takes from the source to the destination. D_{proc} represents the processing delay for each node, which refers to the time required to check the header, determine the correct path and perform other necessary actions. D_{queue} is the queuing delay, which is the time a packet waits in line before transfer. D_{Trans} is the transmission delay at each node, indicating the time required to push all bits to the link. D_{Prop} denotes the propagation delay per node delay, which is the

time required for a signal to be transmitted over the medium from one node to another. In Figure 7, the end-to-end delay is compared with available techniques: HGAR-VANETS achieves 210 ms, ROOP-VANETS records 200 ms and ISFF-VANETS achieves 150 ms. Conversely, the proposed model has a lower delay of 90 ms.

Figure 8 illustrates the overhead calculation of the baseline approaches compared with the proposed SEHMR-VANETS for a varying number of vehicles ranging from 10 to 100. In Figure 8, the transmission status byte is used to denote all messages related to routing, which include route requests, route responses and control messages that are excluded in the payload. Data packets refer to those delivered successfully, indicating that they have reached their destination. When routing overhead is compared with previous techniques, HGAR-VANETS, ROOP-VANETS and ISFF-VANETS record 455, 321 and 287 packets, respectively. Conversely, the proposed SEHMR-VANETS model achieves a notably lower overhead of 112 packets. Therefore, the proposed SEHMR-VANET protocol demonstrates the lowest routing overhead amongst the four protocols.

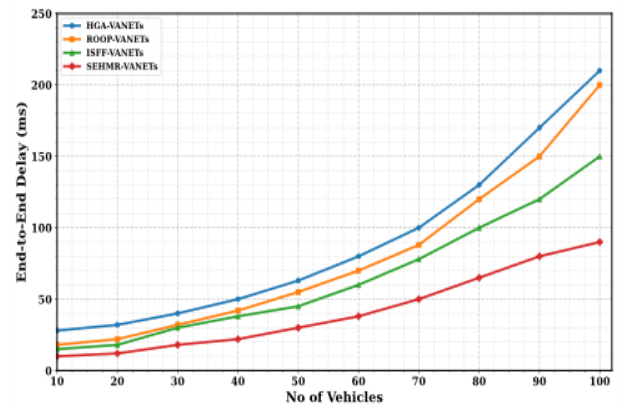


Fig. 7. End-to-End delay calculation

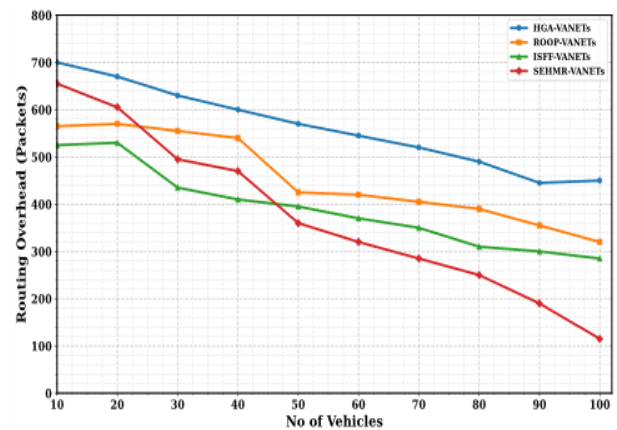


Fig. 8. Routing overhead calculation

**Table 2,
Performance Analysis**

Parameters	HGAR - VANE TS	ROOP- VANE Ts	ISFF- VANET s	SEHMR - VANET s
Energy Efficiency (joules)	198	228	298	322
Throughput (Kbps)	250	265	315	510
Packet Delivery Ratio (%)	83	85	88.2	95
Data Loss Ratio (%)	26	19	11	9
End-to-End Delay (ms)	210	200	150	90
Routing Overhead (Packets)	455	321	287	112

Table 2 presents the simulation results for varying numbers of vehicles to evaluate the performance of the baseline and proposed approaches. The key parameters include the following: energy efficiency, throughput, PDR, data loss ratio, delay and overhead. The SEHMR-VANET system outperforms the HGAR-VANETS [31], ROOP-VANETS [32] and ISFF-VANETS [33] in several metrics, including energy efficiency, throughput and PDR. The proposed model achieves an energy efficiency of 325 joules, surpassing the others by substantial margins. Furthermore, its throughput of 10 Kbps and PDR of 510% surpass those of other approaches. Additionally, SEHMR-VANETS feature a low end-to-end delay of 90 ms and a data loss ratio of 95%, both demonstrating considerable improvements. Furthermore, this model operates with only 112 packets of overhead, which is substantially lower than the other methods, enhancing its overall efficiency.

In addition to the numerical performance enhancements, the SEHMR-VANETS approach demonstrates remarkable practical implications for real-world deployment. This method reduces unnecessary RSU deployment, which enables a decrease in infrastructure and maintenance costs during RSU selection optimisation using the DEA algorithm. Furthermore, the hybrid multi-RSU and clustering strategy shows robust scalability. The SEHMR-VANET approach manages high traffic density and reduces costs and delays in a high-density urban scenario. Conversely, in a low-density rural scenario, the proposed approach ensures

adequate coverage through a limited number of RSUs at low cost. Overall, these features highlight the scalability of the proposed SEHMR-VANET approach for practical V2V applications.

6. Conclusions

This research article presents a novel approach to achieving improved communication between vehicles in rural and urban environments. Most previous approaches rely on static RSU deployment with optimisation strategies that are unsuitable for current vehicular network models. Aiming to improve the quality of vehicular and infrastructure-based communication, SEHMR is proposed as a combination of cost optimisation and effective RSU selection. Considering the varying number of vehicles, the proposed SEHMR-VANETS achieves optimised performance over baseline approaches, including energy efficiency ranging from 198 to 322 joules, throughput from 250 kbps to 510 kbps, PDR from 83% to 95% and mitigated end-to-end delay from 210 ms to 90 ms. Additionally, packet loss is reduced from 26% to 9%, and overhead decreases from 455 to 112 packets compared to the baseline approaches. Overall, this method allows for intelligent communication amongst vehicles, supporting safer movement and more reliable data transmission. Future investigation will focus on incorporating advanced predictive models and exploring the interaction between dynamic RSU placement using machine learning or deep learning approaches to attain maximum efficiency.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors' Contributions

MMH; methodology and validation, SAR; software and writing original draft writing, ANN; review and editing, LA; supervision and project administration.

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الكفاءة الطيفية ونشر هجين متعدد لوحدات جانب الطريق مع تحسين التكلفة في شبكات المركبات المخصصة

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المستخلص

يُمكن تحقيق إدارة مرورية مُحسنة وسلامة مُعززة باستخدام شبكات لامركزية مثل شبكات المركبات المخصصة (VANETs)، والتي تُتيح للمركبات التواصل فيما بينها. تدعم هذه الشبكات الاتصالات الديناميكية والفورية، إلا أنها تُواجه صعوبات فيما يتعلق بقابلية التوسع والأمان واستقرار الشبكة. يهدف هذا البحث إلى تحسين كفاءة الرؤية وخفض التكاليف وتعزيز الاتصال في شبكات المركبات المخصصة (VANETs) باستخدام وحدات جانب الطريق المتعددة (RSUs) وتقنيات التجميع، مما يُحقق فوائد عملية ملموسة. يسعى هذا البحث إلى تحسين كفاءة الاتصال في شبكات المركبات المخصصة (VANETs) من خلال معالجة المشكلات، مثل تأخير الشبكة واستهلاك الطاقة وتكلفة الاتصال. يتمثل الهدف في تحسين موثوقية الشبكة في بيئة مركبات ديناميكية مع وحدات جانب الطريق الثابتة (RSUs)، مما يضمن اتصالاً مستمراً وتقليل النفقات العامة. يُقدم نظام كفاءة الطيف ونشر وحدات جانب الطريق المتعددة الهجين مع تحسين التكلفة (SEHMR) حلاً مبتكراً لتحسين اتصال المركبات. يتضمن النظام تجميع المركبات وجدولة عمليات التجميع وصيانتها بشكل مستمر. من خلال تحليل التوزيع الأولي للمركبات وقيم احتمالية وجودها، تستطيع خوارزمية تحسين التكلفة (DEA) ترشيد التكاليف. فتوضع وحدات جانب الطريق (RSUs) استراتيجياً لتحسين التغطية والاتصال وكفاءة استهلاك الطاقة. تم تقييم هذا النهج من خلال محاكاة مكثفة على NS2 ومجموعة برامج SUMO Mobility، باستخدام مقاييس مثل الكفاءة، ومعدل نقل البيانات، ونسبة تسليم الحزم، وفقدان البيانات، والتأخير من البداية إلى النهاية، والعبء الزائد. تمت مقارنة شبكة SEHMR-VANET المقترحة مع مناهج أساسية مثل HGAR-VANET و ROOP-VANET و ISFF-VANET. تُظهر النتائج أن SEHMR-VANET تحقق كفاءة طاقة أعلى وتأخيراً وفقداناً أقل للبيانات، مما يدل على فعاليتها في تحسين اتصالات حركة المرور.