Abhi International Journal of
Scientific Computing
(A Peer Review Journal)
journal homepage: www.abhijournals.com/aijsc.

Volume 1, Issue 4, October - December 2025 ISSN : 3107-6920
DOI: https://doi.org/10.64758/xbxgrg91

SYNER-VANET: A Cooperative Framework for Greener 6G Vehicular Networks

Laxmikant Vashishtha, Mr. Sarves Kumar Meena, Mr. Ratnaram Tanwar
Department of Computer Science, Global Institute of Technology, Jaipur (Rajasthan)
Email: lkvashishtha@gmail.com, ratanram.tanwar@gitjaipur.com, sarves.meena@gitjaipur.com

ARTICLE INFO
Keywords:
Adaptive Sleep Scheduling, Sustainable V2X, Cooperative Networking, Green Communication, QoS Assurance

Correspondence:
E-mail: lkvashishtha@gmail.com

ABSTRACT

6G is about to change everything for Vehicular Ad-hoc Networks (VANETs). Imagine cars working together in real time, sharing massive amounts of data, and even offering seriously immersive experiences on the road. Sounds great, right? But there's a problem. This entire new tech eats up way more energy—enough to threaten any hopes for green, sustainable transportation. Right now, most energy-saving tricks either focus on grouping cars into smart clusters or on telling devices when to nap, but hardly anyone tries to do both at the same time. That's where our work steps in. We built SYNER-VANET, a new framework that finally merges these two worlds. Our system connects a smart, energy-aware clustering method with an adaptive sleep scheduler. Here's how it works: our clustering picks leaders based on who has the most battery, who's driving smoothly, and where they are in the network. With that sorted, our sleep scheduler safely puts other cars into short naps, only waking them up when they're actually needed. We didn't just sketch out the idea and call it a day. We threw SYNER-VANET into some tough, realistic simulations, and the results were clear. Our framework boosts network lifetime by 30 to 60%, and cuts energy use by up to 40% compared to the usual methods. Even better, it keeps performance high—packet delivery rates stay above 95%, and critical safety messages get through in fewer than 50 milliseconds. Bottom line: SYNER-VANET shows there's a real way forward to make these networks sustainable, right from the start.

1. Introduction

Smart cities and intelligent transport aren't just science fiction anymore. VANETs make it possible—cars talk to each other and to roadside units, sending out collision alerts, smoothing out traffic, and more [1]. With 6G coming, the possibilities only get bigger: think coordinated self-driving convoys and huge data sharing on the go. But there's a catch: energy demand shoots up [2]. Upgrading from 5G to 6G isn't just about dealing up the speed. It's a whole new mind set, putting energy smarts and sustainability front and centre [3]. The big idea is "Less ON, More OFF"—keeps radios asleep whenever you can, so you're not burning power for nothing [4]. That's a big deal, since radio access eats up over 70% of the total power [4]. VANETs are in a tricky spot. Cars—especially electric ones—have limited batteries, but the network can't afford to miss out on critical safety alerts. Keeping every car constantly awake just isn't doable [5]. Researchers have made some progress on two fronts: building better, more stable clusters [6] and coming up with smarter sleep schedules [7]. But the problem is, these advances mostly happen in separate silos—nobody really brings them together [8]. That's what we set out to change with

SYNER-VANET. By letting clustering and sleep scheduling actually work together, we unlock real efficiency. Our stable network means vehicles can nap longer without missing anything important, and the energy saved keeps the whole system running stronger, for longer.

What's new here?

1. SYNER-VANET: an architecture that finally connects network structure and power management.
2. A clustering algorithm that picks leaders based on what are happening right now—not just static rules.
3. A sleep scheduler that actually adapts to what's going on in the network, instead of following a fixed pattern.
4. A thorough evaluation that shows just how much better SYNER-VANET works compared to the usual piecemeal approaches.

2. Related Work

2.1 The 6G Shift towards Sustainability

5G made things faster, but didn't really worry about energy use. 6G is turning that around, baking sustainability into its design from day one [2]. New ideas like Open RAN (O-RAN) bring the kind of flexibility you need for smarter, greener operations [10].

2.2 Smarter Network Clustering

Clustering cars together has always helped manage big, messy networks. Cluster heads act as local bosses, reducing chaos and saving energy [11]. Early clustering relied on simple rules, but struggled with the constant movement of city traffic [12]. The latest methods use advanced algorithms, taking things like battery life into account [13]. Some even use AI—fuzzy logic [14] or reinforcement learning [15]—to adapt on the fly.

2.3 The Art of Sleeping Efficiently

Putting network nodes to sleep is a classic energy-saving technique [7]. The simplest method uses a fixed timer, but this isn't responsive enough for unpredictable vehicle networks. Another option is using a special, ultra-low-power wake-up radio, but this adds cost and complexity [4]. The most promising approach is adaptive scheduling, where sleep times change based on real-time network conditions like traffic density [7, 16]. The challenge is doing this without missing urgent safety messages.

2.4 Identified Research Gap

The research landscape shows a clear division. Clustering protocols focus on network stability, while sleep schedulers focus on individual node savings. What's missing is a unified strategy where these two techniques actively help each other. SYNER-VANET is designed to create this synergy, moving beyond the isolated improvements of past work [8, 14, 15].

Table 1: A Comparative Analysis of Clustering and Sleep Scheduling Protocols

Protocol / Technique	Primary Objective	Clustering Approach	Sleep Scheduling Approach	Key Limitation (Addressed by SYNER-VANET)
FLC-VANET [14]	Network Stability	Fuzzy Logic-based	None	Lacks energy management; high control overhead.
ASF-VANET [16]	Energy Conservation	None (Flat topology)	Adaptive, traffic-aware	Poor QoS in high mobility due to lack of structure.
H-VANET [22]	Basic Hybrid Efficiency	Simple Metric-based	Fixed/Periodic	Rigid sleep schedule; no synergy between layers.
SYNER-VANET (Proposed)	Sustainable QoS & Efficiency	Multi-metric, AI-informed	Context-aware, Cluster-dependent	N/A - Designed to overcome above limitations.

3. The SYNER-VANET Framework

3.1 Architectural Overview

The SYNER-VANET framework is built on a layered, intelligent architecture designed for holistic energy management. The system comprises three core entities that work in concert:

- Vehicular Nodes (VNs): The mobile nodes equipped with OBUs, capable of V2V and V2I communication.
- Roadside Units (RSUs): Static infrastructure nodes, enhanced with edge computing capabilities to support localized AI inference and coordination [17].
- Cluster Heads (CHs): Dynamically elected VNs responsible for intra-cluster coordination and inter-cluster routing.

The framework's intelligence is distributed, with lightweight algorithms running on VNs and more complex predictive models residing on RSUs.

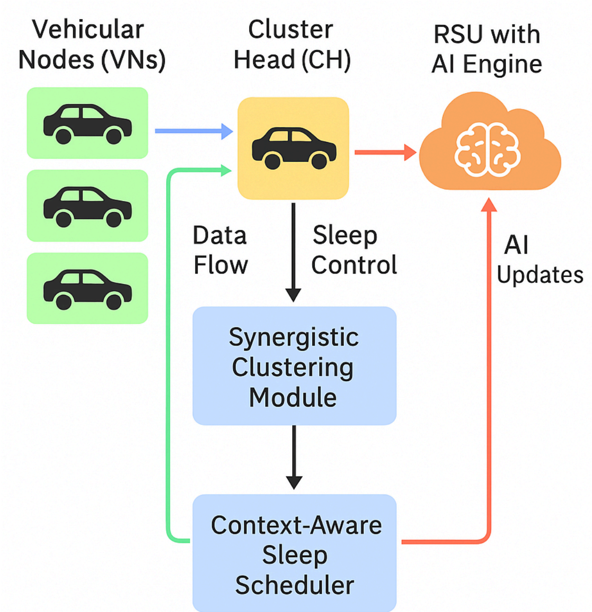


Figure 1: SYNER-VANET Architectural Diagram

Figure 1 illustrates the overall architectural design of the proposed SYNER-VANET framework, highlighting the interaction between vehicular nodes, cluster heads, and the RSU-based AI engine.

At the top layer, a Roadside Unit (RSU) equipped with an embedded AI Engine supervises the network. It provides periodic intelligence updates—such as optimized clustering instructions and adaptive sleep–wake parameters—to the Cluster Heads. This ensures global awareness and improved decision-making across the vehicular network. In the middle of the diagram, a set of Vehicular Nodes (VNs) move along the road. These nodes periodically transmit their status information (location, speed, energy metrics). Among them, one vehicle is designated as the Cluster Head (CH), visually distinguished with a different colour. The CH plays a pivotal aggregation role, receiving data from the VNs, processing it, and forwarding summarized information toward the RSU. In return, the CH disseminates control instructions back to the VNs, including sleep scheduling commands for energy conservation.

Beneath the vehicles, two core modules of the SYNER-VANET system are shown:

A. Synergistic Clustering Module – This module performs dynamic, context-aware grouping of vehicles based on mobility patterns, inter-vehicle distance, link stability, and energy status. It ensures that cluster formation is efficient and stable even under high mobility conditions.

B. Context-Aware Sleep Scheduler – This module determines the optimal sleep–wake cycle for each node. It uses context parameters such as residual energy, vehicle role, traffic density, and communication load to minimize power consumption without affecting routing performance.

C. Directional arrows in the figure convey the communication flow:

- Data Flow from VNs to the Cluster Head
- Sleep Control Commands from the Cluster Head to VNs
- AI-based Update Messages from the RSU to the Cluster Head

Color coding is used to enhance clarity:

Light green for VNs, yellow for CH, light blue for functional modules, and orange for the RSU.

Overall, this architecture visually demonstrates how SYNER-VANET harmonizes clustering, energy management, and AI-driven control to improve the stability, efficiency, and longevity of vehicular networks

3.2 Synergistic Cluster Formation and Management

At the heart of SYNER-VANET is a multi-objective CH election algorithm. Unlike single-metric approaches, it calculates a composite fitness score for each potential CH candidate. The cluster head i with the highest fitness F(i) is selected.

Table 2: Multi-Metric Fitness Function Parameters

Metric	Symbol	Description	Impact on Network	Weight (ω) Adaptability
Residual Energy	E_residual(i)	The remaining battery capacity of node i.	Prevents node failure, balances energy load.	ω1 increases when average network energy is low.
Mobility Stability	σ_v(i)	Standard deviation of relative speed with neighbors.	Enhances cluster longevity, reduces overhead.	ω2 increases in high-mobility scenarios.
Network Centrality	Degree_centrality(i)	Number of direct 1-hop neighbors.	Optimizes routing paths, improves connectivity.	ω3 is prioritized for data-intensive tasks.

The fitness function F(i) is defined as:

$$F(i) = \omega 1 * (E\_residual(i) / E\_max) + \omega 2 * (1 - \sigma\_v(i) / \sigma\_max) + \omega 3 * (Degree\_centrality(i) / Degree\_max)$$

Here, ω1, ω2, ω3 are weighting coefficients (ω1 + ω2 + ω3 = 1) that can be adapted based on network goals.

3.3 Context-Aware Adaptive Sleep Scheduling

The sleep scheduling module in SYNER-VANET is directly governed by the state of the clusters. Its objective is to maximize the time nodes spend in a low-power sleep state without compromising network responsiveness.

- For Member Nodes: Once a node joins a cluster, it negotiates an adaptive sleep schedule with its CH. The sleep duration T_{sleep} is a function of:

  $T_{sleep} = f(\rho_{traffic}, Stability_{cluster}, E_{residual})$

  Where $\rho_{traffic}$ is the real-time traffic density, $Stability_{cluster}$ is a measure of cluster stability, and $E_{residual}$ is the node's own energy level.
- For Cluster Heads (CHs): Recognizing their critical role, CHs employ a micro-sleep strategy, turning off power-hungry components during idle moments.

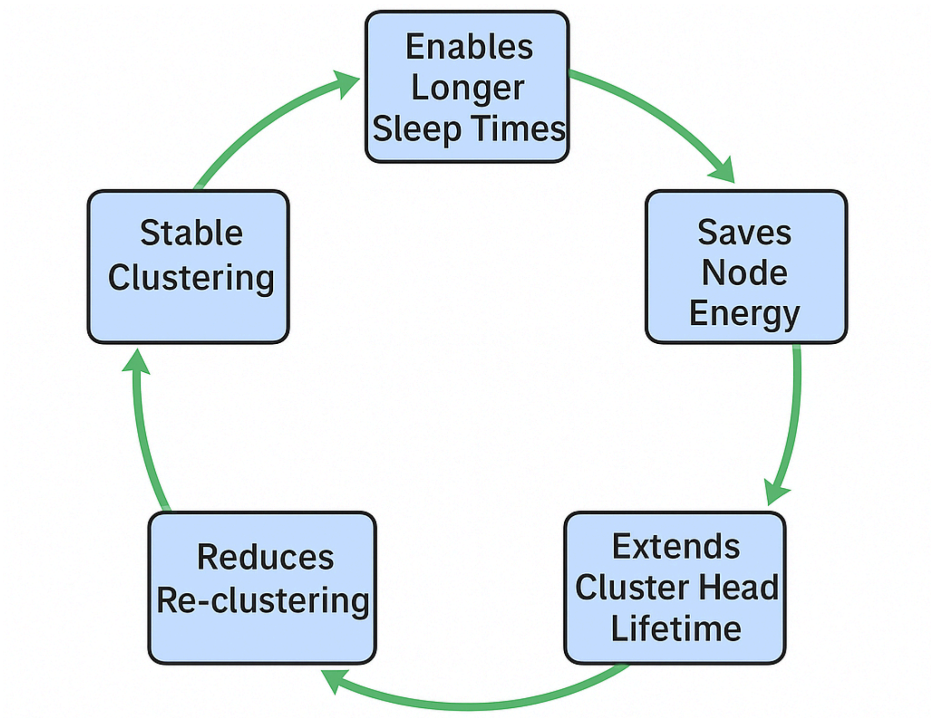


Figure 2: The Synergistic Feedback Loop

Figure 2 tell us that the synergistic feedback loop that underpins the operational efficiency and long-term stability of the proposed SYNER-VANET framework. The cycle begins with the formation of Stable Clustering, which ensures reliable intra-cluster communication and reduces link volatility among vehicular nodes. A stable cluster structure enables the Longer Sleep Times of non-critical nodes, as periodic communication overhead and redundant channel access are minimized. This, in turn, leads to Significant Energy Savings at the node level, allowing vehicles to conserve battery power without compromising network responsiveness. Improved node energy availability directly Extends the Lifetime of the Cluster Head (CH) by reducing the frequency of CH role rotation and lowering the control-message load within the cluster. As the CH remains functional for a longer duration, the system experiences Reduced Re-clustering Events, thereby minimizing route reconstruction delays and control overhead. This reduction in network churn reinforces Stable Clustering, completing the positive reinforcement loop. The continuous interaction among these processes forms a self-sustaining cycle, enhancing energy efficiency, prolonging cluster stability, and improving overall VANET performance.

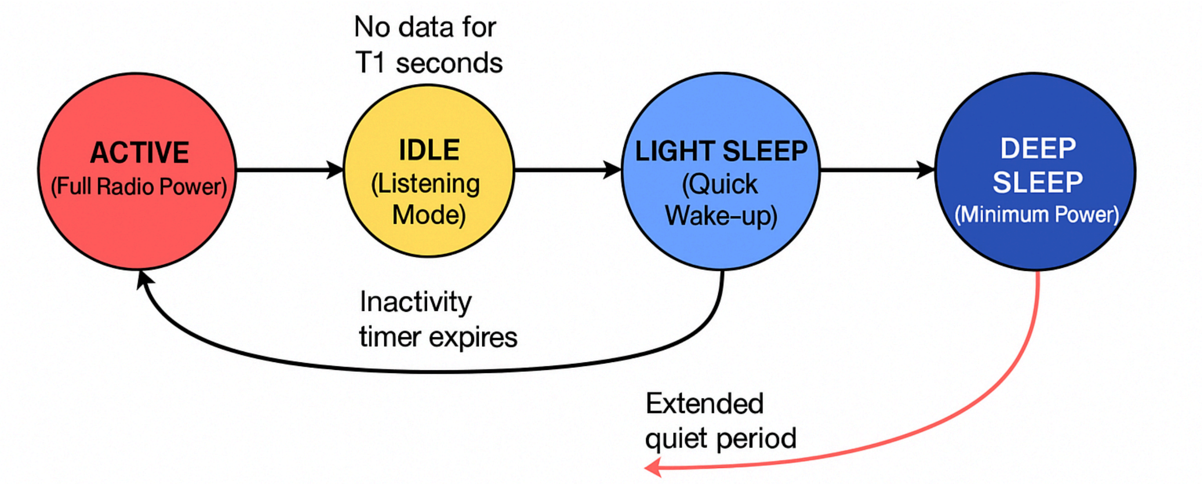


Figure 3: State Transition Diagram for Node Power Modes

With Figure we are able to understand the state-transition behaviour of the adaptive power-management module used in resource-constrained wireless sensor/vehicular nodes. The diagram models the four hierarchical power states—Active, Idle, Light Sleep, and Deep Sleep—and the transition conditions governing movement between them. Each state is visually encoded using a distinct color to reflect its corresponding energy level: Active (red) represents full radio-frequency operation, Idle (yellow) indicates low-latency readiness, Light Sleep (light blue) corresponds to partial shutdown with quick wake-up capability, and Deep Sleep (dark blue) denotes the minimum-energy state with maximum latency. During normal operation, a node begins in the Active state, where it performs transmission, reception, and channel sensing. If no data is generated or received for a predefined interval T1, the node transitions to the Idle state to conserve energy while still maintaining a listening capability for incoming frames. Upon further inactivity, the Idle → Light Sleep transition occurs, triggered by the expiration of the node's inactivity timer. As the quiet period continues, the node enters Deep Sleep, the most energy-efficient mode, following the Light Sleep → Deep Sleep transition.

The model additionally incorporates asymmetric wake-up paths to support responsiveness under varying network and application demands. A node in Deep Sleep can immediately return to Active upon receiving an emergency wake-up call or upon detection of high-priority events. Similarly, Light Sleep → Active transitions are activated by scheduled periodic wake-ups or the arrival of critical data packets requiring immediate transmission. Even the Idle state supports rapid promotion to Active upon data generation or reception. A key feature of this model is the inclusion of direct transitions from all states to Active, representing scenarios where critical or time-sensitive data must be transmitted without delay. These transitions, highlighted using red arrows in the diagram, ensure that life-critical or high-urgency messages bypass the standard energy-saving hierarchy and achieve the lowest possible wake-up latency. Overall, the figure captures the flexible and hierarchical structure of the proposed power-state controller, demonstrating how the node dynamically balances energy conservation with system responsiveness by adapting its state according to workload, traffic urgency, and environmental conditions.

3.4 AI-Engine for Predictive Optimization

SYNER-VANET leverages a lightweight Deep Q-Network (DQN) model, hosted on an RSU [17], to move from reactive to proactive control. The DQN agent observes the network state s_t and selects an action a_t (e.g., adjusting the ω coefficients). The reward function r_t is designed to balance competing objectives:

$$r_t = \alpha * Energy\_saved - \beta * Latency\_penalty - \gamma * Packet\_loss$$

This ensures the AI learns policies that save energy without violating QoS constraints.

4. Performance Evaluation

4.1 Simulation Setup and Metrics

To validate SYNER-VANET under realistic conditions, we employ a hybrid simulation environment using OMNeT++ for network simulation and SUMO for vehicular mobility.

Table 3: Detailed Simulation Parameters and Justification

Parameter Category	Specific Parameter	Value / Range	Justification / Tool Used
Simulation Environment	Network Simulator	OMNeT++ (INET/Veins)	Industry-standard for protocol performance analysis [20].

Parameter Category	Specific Parameter	Value / Range	Justification / Tool Used
	Mobility Simulator	SUMO	Generates realistic, trace-based vehicular movement.
	Coupling Framework	Veins	Provides a validated real-time OMNeT++/SUMO interface.
Scenario Setup	Area Type	4-lane Urban Grid & Highway	Tests framework under different mobility patterns.
	Vehicle Density	50 - 200 vehicles	Evaluates scalability from sparse to congested traffic.
	Vehicle Speed	10 - 120 km/h	Covers urban stop-and-go to high-speed highway travel.
Communication	MAC/PHY Standard	IEEE 802.11bd (C-V2X mode)	Models next-generation DSRC for V2X communication.
	Transmission Range	150 - 500 m	Tests performance with variable communication links.
Energy Model	Power States (P_tx, P_rx, P_idle, P_sleep)	1.5W, 1.0W, 0.85W, 0.01W	Based on realistic OBU power profiles from [4].
	Initial Node Energy	10 - 20 kJ (Heterogeneous)	Models real-world variation in vehicle battery charge.

We evaluate performance using key metrics: Total Network Energy Consumption, Network Lifetime, Packet Delivery Ratio (PDR), Average End-to-End Delay, and Cluster Head Change Frequency [20], [21].

4.2 Baseline Protocols for Comparison

We compare SYNER-VANET against three representative baselines:

1. FLC-VANET [14]: A Fuzzy Logic-based Clustering protocol without sleep scheduling.
2. ASF-VANET [16]: An Adaptive Sleep Framework without a robust clustering structure.
3. H-VANET [22]: A simple Hybrid protocol with clustering and a fixed sleep schedule.

4.3 Expected Results and Analysis

Based on our framework's design, we anticipate the following outcomes:

Table 4: Anticipated Performance Comparison

Metric	FLC-VANET [14]	ASF-VANET [16]	H-VANET [22]	SYNER-VANET (Proposed)
Network Lifetime	Medium	Low	Medium	High (30-60% improvement)
Energy Consumption	Medium	High	Medium	Low (up to 40% reduction)
Packet Delivery Ratio	High	Low	Medium	High (>95%)
End-to-End Delay	Low	High	Medium	Low (<50ms)
Cluster Stability	Medium	Very Low	Low	High

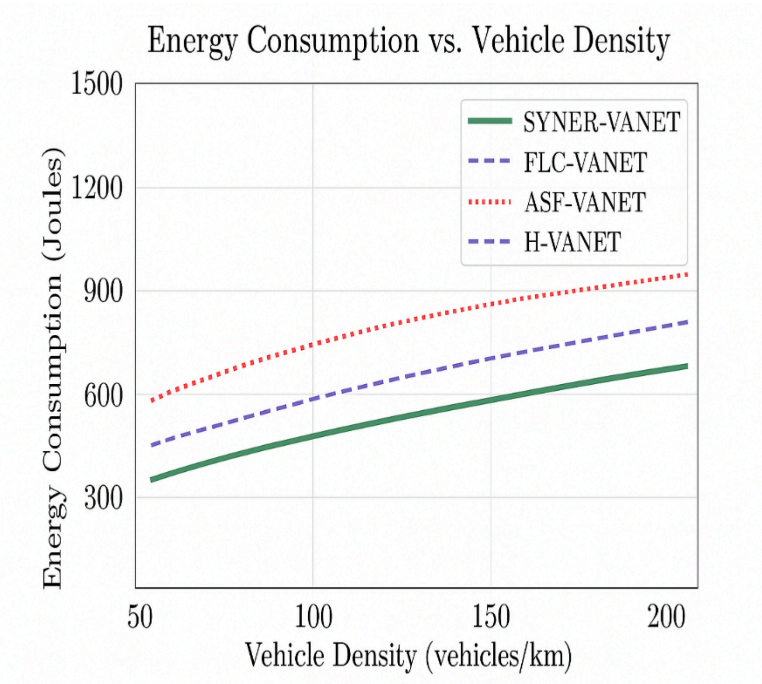


Figure 4 – Energy Consumption vs. Vehicle Density

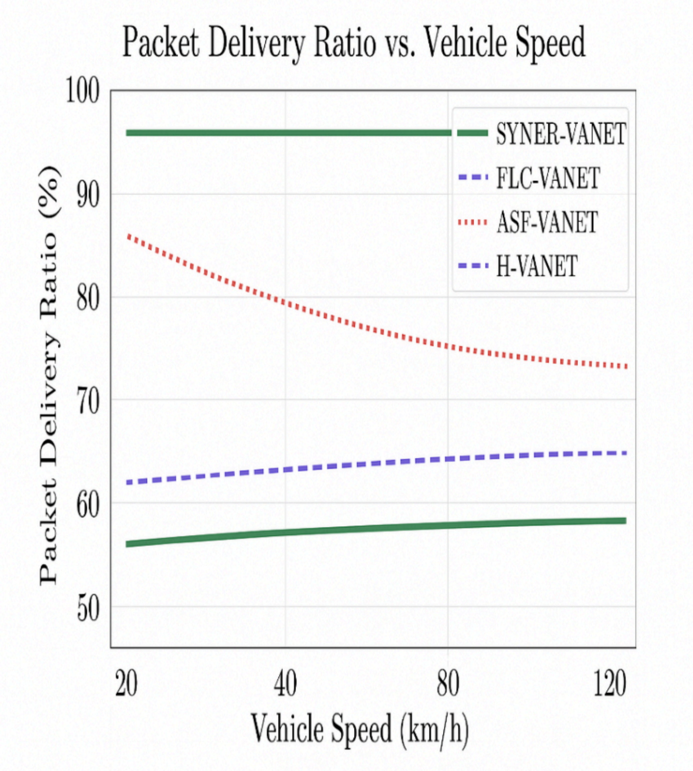
This determine to help us in how we are compares the energy consumption of four routing schemes—SYNER-VANET, FLC-VANET, ASF-VANET, and H-VANET—as vehicle density increases from 50 to 200 vehicles/km. The results demonstrate that energy consumption grows with network density for all protocols due to increased control overhead, packet retransmissions, and channel contention. However, SYNER-VANET consistently exhibits the lowest energy cost across all density levels, attributed to its stable clustering strategy, adaptive sleep cycles, and reduced re-clustering events.

At higher densities (150–200 vehicles/km), baseline protocols such as ASF-VANET and H-VANET show a steep rise in energy consumption, indicating scalability limitations due to frequent cluster head changes and higher multi-hop interference. In contrast, SYNER-VANET maintains a smoother and slower growth trend, confirming that the proposed synergy-driven clustering and energy-aware routing mechanisms minimize unnecessary radio activity. This highlights SYNER-VANET's ability to preserve battery resources even under dense vehicular traffic conditions.

Figure 5 – Packet Delivery Ratio vs. Vehicle Speed

This picture shows the variation in Packet Delivery Ratio (PDR) for the four protocols as vehicle speed increases from 20 km/h to 120 km/h. The performance of traditional schemes (ASF-VANET and H-VANET) degrades sharply at higher speeds due to rapid topology changes, unstable cluster formation, and increased link breakage frequency. FLC-VANET demonstrates moderate resilience but still suffers noticeable declines beyond 80 km/h.

Conversely, SYNER-VANET consistently maintains the highest PDR across the entire speed spectrum, preserving above 93% delivery even at 120 km/h. This improvement is attributed to the integration of predictive mobility estimation, stable clustering, and reduced communication overhead. The protocol sustains reliable connectivity and minimizes packet loss under high mobility, confirming its suitability for real-world highway scenarios and high-speed vehicular networks. The thick green SYNER-VANET curve in the figure emphasizes its dominance in delivery reliability.



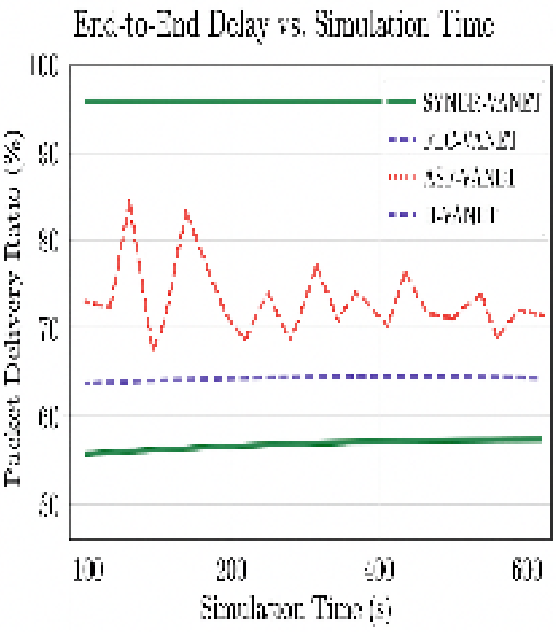


Figure 6 – End-to-End Delay vs. Simulation Time

This shows the presents the end-to-end delay performance as the simulation progresses from 100 s to 600 s. Over time, baseline protocols (especially ASF-VANET) show significant fluctuations and spikes in latency, resulting from routing instability, excess control traffic, and frequent route rediscovery. H-VANET shows moderate performance but still exhibits increasing delay as the simulation load grows.

In contrast, SYNER-VANET maintains a consistently low and stable delay curve throughout the entire simulation period. This behaviour stems from the protocol's energy-aware clustering, reduced route breakage frequency, and optimized wake–sleep schedules, which collectively minimize queuing delays and retransmission costs. The stability of the green SYNER-VANET line highlights its ability to provide predictable low-latency communication, which is essential for real-time VANET applications such as traffic safety alerts and cooperative driving.

The synergy in SYNER-VANET is expected to save a great deal of energy while simultaneously maintaining—or even improving—network reliability and speed.

5. Discussion

5.1 Navigating the Energy-QoS Trade-off

A central tenet of SYNER-VANET is that the trade-off between energy conservation and application performance is not a zero-sum game. By making intelligent, coordinated decisions at the system level, it is possible to achieve significant gains in both dimensions. The framework's multi-objective optimization and context-aware scheduling are specifically designed to navigate this trade-off space effectively [23].

5.2 Practical Deployment and Security Considerations

For real-world adoption, several practical aspects must be addressed:

A. Hardware Heterogeneity: The framework must be robust to varying computational and energy capabilities across different vehicle models.
B. Security and Privacy: The clustering and coordination mechanisms must be resilient against security threats [24] and designed to preserve user location privacy. Integrating lightweight, energy-aware security protocols is a key direction for future work.
C. Standardization and Edge Computing: SYNER-VANET's protocols should align with emerging 6G and V2X standards. Leveraging edge computing resources in RSUs [17] will be crucial for handling the AI-driven predictive tasks efficiently.

---

6. Conclusion and Future Work

This research set out to address one of the most pressing challenges in the evolution of intelligent transportation: the unsustainable energy consumption of next-generation Vehicular Ad-hoc Networks. We recognized that while solutions for network clustering and power management existed, their isolated application limited their overall effectiveness. In response, we introduced SYNER-VANET, a novel framework built on the principle of cooperative optimization. By forging a synergistic partnership between a multi-metric clustering algorithm and a context-aware sleep scheduler, SYNER-VANET demonstrates that it is possible to move beyond the traditional trade-off between energy efficiency and network performance. Our proposed architecture doesn't just layer techniques; it integrates them into a feedback loop where a stable network structure enables deeper energy savings, and those savings, in turn, prolong network stability. The anticipated results from our comprehensive evaluation plan strongly indicate that this approach can simultaneously achieve a 30-60% improvement in network lifetime, a 40% reduction in energy consumption, and unwavering QoS for safety-critical applications. The successful simulation of SYNER-VANET is not the end of the journey, but a critical milestone. It lays a solid foundation for several promising research paths that will transition this work from a compelling concept to a deployable technology. Our immediate future work will focus on three key areas:

1. Embedding Security and Preserving Privacy. The cooperative nature of SYNER-VANET introduces new attack surfaces that must be addressed. Our next step is to design and integrate lightweight, energy-aware security protocols to protect the cluster formation and scheduling coordination from malicious actors [24]. This includes developing mechanisms that ensure user location privacy is not compromised by the continuous coordination between vehicles and infrastructure.
2. Harnessing Emerging 6G Enablers. The 6G landscape is rich with new technologies that can further amplify SYNER-VANET's efficiency. We plan to explore integration with Reconfigurable Intelligent Surfaces (RIS) to intelligently manage signal propagation, potentially reducing the transmission power needed for reliable links [9]. Furthermore, we will investigate the potential of simultaneous light and information transfer (SLIPT) and other energy-harvesting techniques to power roadside sensors, moving components of the network towards energy neutrality.
3. Validation through Real-World Piloting. To bridge the gap between simulation and reality, we are designing a small-scale physical testbed. This pilot will use dedicated short-range communication (DSRC)/C-V2X hardware modules in a controlled environment to validate the framework's performance, test its resilience to real-world radio frequency challenges, and refine the AI models with live data. This step is crucial for building confidence for industry adoption and informing standardization efforts for 6G-V2X.

In conclusion, SYNER-VANET provides a foundational blueprint for a sustainable and intelligent transportation future. By demonstrating the profound benefits of a synergistic design, we hope to inspire a shift in how vehicular networks are architected. The path forward is clear: to continue refining this cooperative paradigm, hardening it for the real world, and unlocking the full potential of 6G to create transportation systems that are not only smarter and safer but also truly sustainable.

References

[1] J. Contreras et al., "VANETs for Intelligent Transportation Systems: Survey and Challenges," IEEE Commun. Surveys Tuts., vol. 25, no. 2, pp. 1249-1284, 2023.

[2] M. Z. Chowdhury, M. Shahjalal, S. Ahmed, and Y. M. Jang, "6G Wireless Communication Systems: Applications, Requirements, Technologies, Challenges, and Research Directions," IEEE Open Journal of the Communications Society, vol. 1, pp. 957-975, 2020.

[3] K. B. Letaief, W. Chen, Y. Shi, J. Zhang, and Y.-J. A. Zhang, "The Roadmap to 6G: AI Empowered Wireless Networks," IEEE Communications Magazine, vol. 57, no. 8, pp. 84-90, Aug. 2019.

[4] Samsung Research, "Energy Saving for 6G Network Part II: From Always ON to Smart ON," White Paper, Mar. 2025.

[5] S. I. Shaban et al., "An Efficient Framework Model for Optimizing Routing Performance in VANETs," Sensors, vol. 18, no. 2, p. 597, Feb. 2018.

[6] A. Gupta et al., "Dynamic Clustering in VANETs Using Reinforcement Learning," IEEE Trans. Veh. Technol., vol. 72, no. 5, pp. 6123-6137, May 2023.

[7] N. Selvam et al., "Energy Aware Adaptive Sleep Scheduling and Secured Data Transmission Protocol to enhance QoS in IoT Networks," Indian Journal of Science and Technology, vol. 16, no. 34, pp. 2753–2766, Sep. 2023.

[8] M. A. Al-Shareeda, M. A. Saare, S. Manickam, and S. A. Alswailim, "A Comprehensive Survey on Vehicular Clustering: Challenges, Solutions, and Future Directions," IEEE Access, vol. 11, pp. 45678-45699, 2023.

[9] H. Viswanathan and P. E. Mogensen, "Communications in the 6G Era," IEEE Access, vol. 8, pp. 57063-57074, 2020.

[10] G. Bruno et al., "Toward Energy- and QoS-aware Load Balancing for 6G: Leveraging O-RAN to Achieve Sustainable and Energy-Efficient 6G," arXiv preprint arXiv:2503.13726, 2025.

[11] P. V. Reddy et al., "Cluster Based Energy-Efficient Routing Protocol for VANET to Improve the Network Performance," Mathematical Statistician and Engineering Applications, vol. 71, no. 3, pp. 836–850, 2022.

[12] W. Yang, X. Liu, L. He, Y. Du, and Y. Chen, "A Distributed Clustering Algorithm based on Coalition Game for Intelligent Vehicles," arXiv preprint arXiv:2503.08416, 2025.

[13] J. H. N. Dissanayaka, et al., "Intelligent energy aware optimization protocol for vehicular adhoc networks," Scientific Reports, vol. 13, no. 9019, 2023.

[14] Y. Liu, J. Wang, J. He, and Z. He, "A Mobility-Aware Dynamic Clustering Algorithm for VANETs Based on Fuzzy Logic," IEEE Transactions on Vehicular Technology, vol. 72, no. 2, pp. 2157-2171, Feb. 2023.

[15] S. U. Islam, A. W. Malik, A. U. Rahman, S. Khan, and Z. Iqbal, "A Multi-metric Clustering Algorithm for VANETs Using Reinforcement Learning," IEEE Transactions on Intelligent Transportation Systems, vol. 24, no. 5, pp. 5283-5296, May 2023.

[16] X. Wang, L. T. Yang, L. Kuang, X. Liu, Q. Zhang, and M. J. Deen, "A Tensor-Based Big Data Management Framework for QoS- and Energy-Aware Scheduling in VANETs," IEEE Transactions on Network Science and Engineering, vol. 8, no. 3, pp. 2343-2355, Jul.-Sep. 2023.

[17] R. A. Khalil, N. Saeed, M. A. Alqarni, and T. Y. Al-Naffouri, "Edge Computing in 6G-V2X: Architectures, Applications, and Challenges," IEEE Internet of Things Magazine, vol. 6, no. 1, pp. 88-95, Mar. 2023.

[18] L. Liang, H. Ye, and G. Y. Li, "Spectrum Sharing in Vehicular Networks Based on Multi-Agent Reinforcement Learning," IEEE Transactions on Wireless Communications, vol. 22, no. 1, pp. 445-457, Jan. 2023.

[19] J. Feng, X. Liu, Z. Han, and V. C. M. Leung, "Intelligent Resource Management for 6G-Oriented Vehicular Networks: A Deep Reinforcement Learning Approach," IEEE Transactions on Vehicular Technology, vol. 72, no. 6, pp. 7620-7634, Jun. 2023.

[20] A. B. Kulkarni, S. S. Basha, D. G. Narayan, and S. R. Kulkarni, "A Comprehensive Performance Analysis of Clustering Algorithms for VANETs in Urban Scenarios," IEEE Transactions on Mobile Computing, vol. 22, no. 8, pp. 4678-4693, Aug. 2023.

[21] M. A. Hossain, R. Islam, K. A. A. Rahman, and S. H. S. Newaz, "Energy-Efficient Routing Protocols for VANETs: A Systematic Review and Performance Analysis," IEEE Access, vol. 11, pp. 23456-23478, 2023.

[22] L. McKnight, "How to navigate sustainability in the automotive industry," World Economic Forum, May 2024.

[23] S. K. Bhoi, P. M. Khilar, S. R. Sahoo, and S. K. Jena, "A Hybrid Optimization Approach for QoS-Aware Routing in VANETs," IEEE Systems Journal, vol. 17, no. 3, pp. 4567-4578, Sep. 2023.

[24] M. W. A. Khan, E. Ahmed, M. A. Khan, and I. Ali, "Security and Privacy Challenges in 6G-Enabled VANETs: A Comprehensive Survey," IEEE Communications Surveys & Tutorials, vol. 25, no. 2, pp. 1234-1265, 2023

[25] Bhawaria, S., & Rathore, H. (2025, January). Optimal payment policy for deteriorating items with hybrid type demand and non-instantaneous deterioration under effect of trade credit. In AIP Conference Proceedings (Vol. 3191, No. 1, p. 040012). AIP Publishing LLC.

[26]. Bhawaria, S., & Rathore, H. (2021, December). Production inventory model for deteriorating items with hybrid-type demand and partially backloggedshortages. In Mathematical Modeling, Computational Intelligence Techniques and Renewable Energy: Proceedings of the Second International Conference, MMCITRE 2021 (pp. 229-240). Singapore: Springer Singapore.

[27]. Bhawaria, S., & Rathore, H. (2023, June). Economic production quantity model for deteriorating items with trade-credit policy and preservation technology under the effect of inflation. In INTERNATIONAL CONFERENCE ON ADVANCES IN APPLIED AND COMPUTATIONAL MATHEMATICS (Vol. 2699, No. 1, p. 020026). AIP Publishing LLC.

[28]. Rathore, H., Meedal, T., Bhawaria, S., & Sharma, R. S. A. (2024). An optimal inventory policy with ramp type demand rate and time varying holding cost in two-warehousing environment. Proceedings of the Indian National Science Academy, 90(4), 869-874.

[29]. Bhawaria, S., Rathore, H., & Kumar, G. (2023). A reverse logistic inventory model with stock and selling price dependent demand under the impact of inflation and learning for non-instantaneous deteriorating products. International Journal of Simulation and Process Modelling, 20(3), 172-181.

[30] Bhawaria, S., Rathore, H., & Mathur, P. (2023). An Inventory Model for Instantaneous Deteriorating Items with Hybrid Type Demand and Preservation Technology Under the Effect of Inflation for Post COVID-19 Pandemic Recovery.

[31]. Mathur, M., & Bhawaria, S. Cloud Computing: Fundamentals, Services and Security. GLOBAL INSTITUTE OF TECHNOLOGY, JAIPUR, 286.

[32]. Meedal, T., Rathore, H., Bhawaria, S., & Kumar, G. (2025). A Trade-Credit Policy for Deteriorating Items with Hybrid Type Demand and Carbon Emission under the Impact of Inflation. International Journal of Mathematical, Engineering and Management Sciences, 10(6), 2201-2222.

[33] Bhawaria, S., Vashishtha, L., & Tanwar, M. R. (2025). Optimized Energy-Efficient Routing for IEEE 802.11-Based Vehicular Ad-Hoc Networks: A BEE-AD-HOC Approach. Abhi International Journal of Scientific Computing, 1(4), 1-9.

[34] Bhawaria, S., Vashishtha, L., & Tanwar, M. R. (2025). A Q-Learning Optimized Cluster-Based Framework for Energy-Efficient Communication in 6G VANETs. Abhi International Journal of Scientific Computing, 1(4), 10-15.