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Emerging Trends in Smart Green IoV: Vehicle-To-Everything (V2X) in The Electric Vehicle Era

Shruti Gupta[1], Mr. Ashish Bhargaya[2]
[1]M. Tech., Scholar, guptashruti1116@gmail.com, EE Department BHABHA University, Bhopal, India
[2]Assis. Prof., BHABHA University Bhopal, India

Abstract *– This paper evolution of the Internet of Vehicles (IoV) is shaping the future of intelligent transportation, especially with the rapid adoption of electric vehicles (EVs). This thesis explores the emerging trends in Smart Green IoV, focusing on Vehicle-to-Everything (V2X) communication in the context of electric mobility. The integration of V2X technologies, such as Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Grid (V2G), is transforming the way vehicles interact with each other and their surroundings, promoting sustainability and energy efficiency. This study investigates the role of V2X in enhancing road safety, reducing energy consumption, and supporting smart grid integration, highlighting how these advancements can contribute to a sustainable and intelligent transportation ecosystem.*

Key challenges in implementing Smart Green IoV, including communication reliability, data security, and infrastructure compatibility, are analyzed, alongside strategies to address these barriers. Additionally, the thesis reviews cutting-edge technologies such as artificial intelligence, edge computing, and 5G networks, which are driving the development of more efficient V2X communication systems. The findings aim to provide insights into future directions for researchers and industry stakeholders, offering recommendations for optimizing the use of V2X in electric vehicles. Ultimately, the research underscores the potential of Smart Green IoV to foster an eco-friendly and connected future for transportation.

Keywords: Internet of Vehicles (IoV), Vehicle-to-Everything (V2X), Electric Vehicles (EVs), Sustainable Transportation, Smart Green IoV, Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Grid (V2G).

I. INTRODUCTION

The rapid evolution of electric vehicles (EVs) is reshaping the global automotive landscape, driven by the need for sustainable and environmentally friendly transportation solutions. At the forefront of this revolution is the concept of the Internet of Vehicles (IoV), which leverages advanced communication technologies to create a connected ecosystem where vehicles, infrastructure, pedestrians, and networks interact seamlessly. Vehicle-to-Everything (V2X) communication, a critical component of IoV, facilitates real-time data exchange among vehicles and their surroundings, enhancing safety, efficiency, and user experience.

In the era of electric vehicles, the integration of V2X communication within the IoV framework is witnessing significant advancements. The push toward smart, green mobility has introduced new challenges and opportunities, particularly in optimizing energy management, ensuring data security, and supporting autonomous driving. Emerging technologies such as artificial intelligence, edge computing, and blockchain are being explored to address these challenges and unlock the full potential of IoV in the EV domain.

This paper investigates the emerging trends in smart green IoV with a focus on V2X communication in the context of electric vehicles. By analyzing current developments and future directions, it highlights how V2X is transforming transportation into a sustainable, intelligent, and interconnected system. This exploration underscores the pivotal role of innovative solutions in shaping the future of mobility, fostering a greener and more efficient transportation ecosystem.

Several technologies underpin IoV, each essential for creating a robust and reliable network. High-speed wireless networks, including 5G, provide the low latency and bandwidth necessary for data to be transmitted and received seamlessly between vehicles and the cloud. This connectivity enables immediate responses to real-time conditions on the road, enhancing both safety and efficiency. Another cornerstone of IoV is edge computing, which processes data closer to its source—either within the vehicle or nearby servers—instead of relying solely on distant cloud servers. Edge computing supports immediate data processing and decision-making, which is critical for applications requiring quick response times, such as hazard detection or dynamic route optimization. Additionally, artificial intelligence

(AI) and machine learning (ML) are embedded within IoV systems to analyze data streams, predict trends, and enable proactive maintenance or operational adjustments.

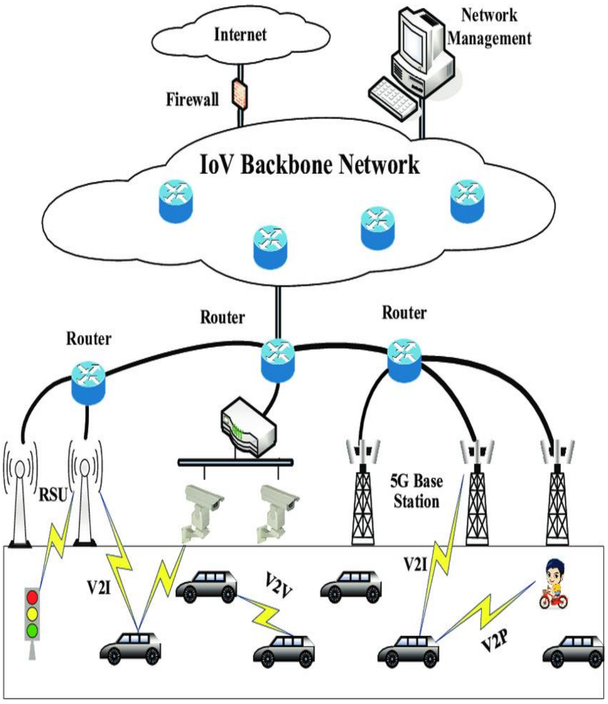

Figure 1 IoV Backbone network

II. V2X COMMUNICATION

Vehicle-to-Everything (V2X) communication is a groundbreaking technology that enables vehicles to interact with each other, surrounding infrastructure, pedestrians, and more. As an essential component of intelligent transportation systems, V2X enhances safety, optimizes traffic flow, and supports the shift toward autonomous and electric vehicles. V2X transforms the conventional transportation model, which traditionally operates independently, into an integrated, connected ecosystem where data sharing enhances the driving experience, promotes safety, and supports sustainable urban mobility.

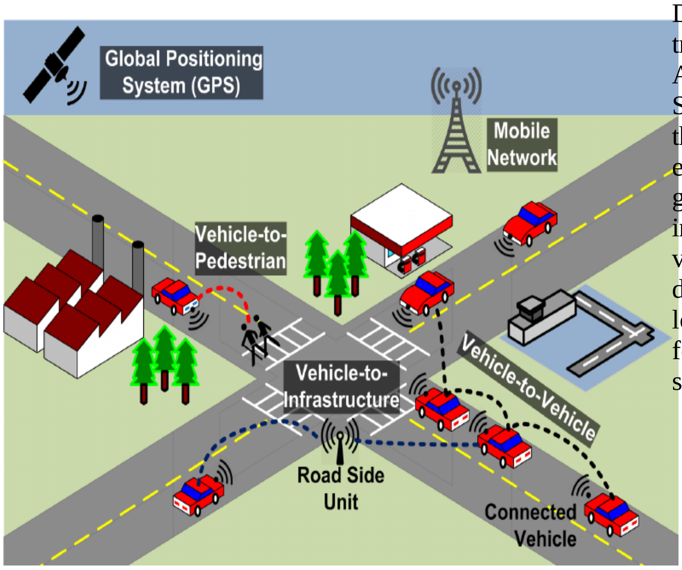

Figure 2: V2X Communications

V2X communication encompasses various communication types, including Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), and Vehicle-to-Network (V2N), each serving unique functions within the larger ecosystem. Together, these connections create a “smart” roadway environment where vehicles are continuously informed about road conditions, traffic signals, pedestrian movements, and potential hazards, enabling faster, data-driven decisions that improve both safety and efficiency.

III. METHOD

The proposed method for analyzing the future trends in Smart Green Internet of Vehicles (IoV) in the era of Electric Vehicles (EVs) involves a multi-faceted approach that encompasses data collection, analysis, and the development of an integrated framework. This method will consist of the following key components:

1. **Literature Review**
2. **Identifying Key Components of Smart Green IoV**

Future green Internet of Vehicles (IoV) systems are anticipated to be organized in a hierarchical manner, integrating distributed edge computing components with a centralized remote computing server. A pivotal technology facilitating this integration is Software-Defined Networking (SDN), which has gained significant traction in the design of 5G-enabled vehicular networks. As illustrated in Figure 2, the architecture of the green SDN-based IoV comprises a cloud server functioning as the central SDN controller. Distributed SDN-enabled edge computing nodes (SDN-ECs) are responsible for gathering vehicular traffic data and processing information requests. When the SDN-ECs can fulfill vehicular requests (such as computation tasks) within designated timeframes, they handle these requests locally. If they are unable to do so, the SDN-ECs may forward the requests to other SDN-ECs or to the cloud server.

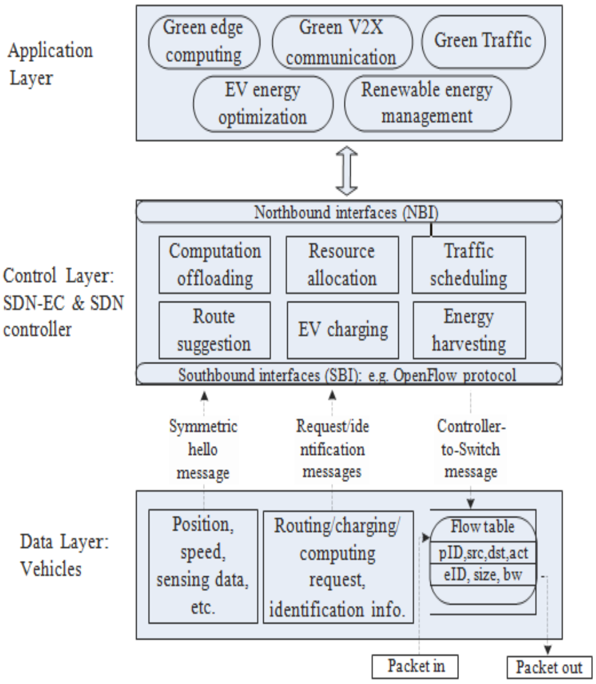

Figure 3: Proposed Framework

Figure 3 presents the implementation framework for the green SDN-based IoV architecture, which includes three primary layers: the application layer, the control layer, and the forwarding layer.

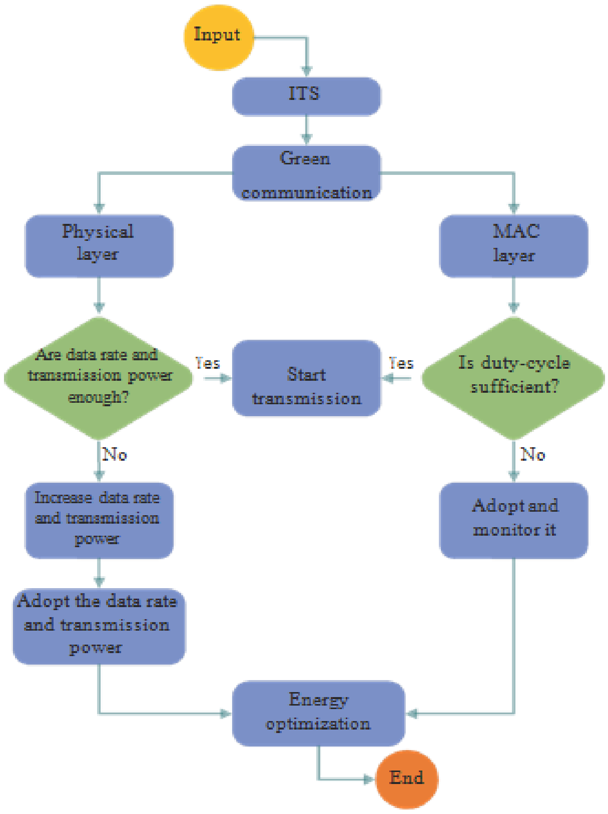

Figure 4: Proposed flow chart

The application layer hosts various green IoV applications, such as green vehicle-to-everything (V2X) communication and green edge computing services. The control layer encompasses the specific implementation strategies, including the allocation of communication and computation resources, as well as intelligent traffic management solutions. The data layer primarily consists of vehicles and pedestrians, who can upload traffic data (like position and speed) and submit information requests (such as routing and computation inquiries) to the control layer. Once the SDN controller analyzes the collected traffic data and requests, it determines the appropriate scheduling, routing, and computing actions. These decisions are communicated to the respective network nodes through controller-to-switch messages. The scheduling directives are recorded in a flow table; for instance, each routing rule is stored as a flow entry that details the specific request, source and destination nodes, and the associated actions to be taken.

By activating the adaptive employment scheme, or 'work' mode, on relaying vehicles, these vehicles can adjust the computational resources they offer based on changing communication needs, effectively reducing energy consumption associated with unnecessary forwarding operations. Parked vehicles, due to their extended idle times and widespread distribution, can serve as road relay nodes to facilitate communication for moving vehicles that may be distant or obstructed by barriers. To prevent energy depletion from continuously operational parked vehicles, a method has been proposed to optimize energy use when these vehicles act as relay nodes, enhancing connectivity for driving vehicles. This approach categorizes moving vehicles into different clusters based on their communication ranges, selectively activating only certain parked vehicles to enter 'work' mode, thereby conserving energy.

To minimize energy usage in parked vehicles, a Markov model is utilized to analyze energy consumption, accompanied by a dynamic work mode selection algorithm. The issue of relay selection has garnered significant attention in the design of energy-efficient vehicular routing protocols. Key factors influencing relay selection include the types of vehicles involved (e.g., public versus private), the driving status of surrounding vehicles, and the distance from the current location to the next intersection.

In one study, relaying vehicles are chosen based on their position, directional flow, and message delivery time. A vehicle direction (VD)-based authorization selection model reduces unnecessary message broadcasting in vehicular routing protocols, thereby lowering communication overhead and enhancing energy efficiency. Similarly, other research leverages vehicle driving direction, traffic density, and inter-vehicle distances to identify energy-efficient relay vehicles. A geographical routing algorithm demonstrated superior effectiveness compared to traditional protocols such as ad hoc on-demand distance vector and dynamic source routing (DSR).

Another study proposes a method for selecting routing paths based on the total energy consumption of relay vehicles between source and destination nodes. In the GreeAODV routing protocol, energy consumption is calculated at the point where a relay node receives and transmits packets. The combined optimization of relay selection and transmission resource allocation emerges as a promising strategy for reducing energy usage in vehicular networks. By identifying energy-efficient relay vehicles and appropriately allocating spectrum and power resources, both communication quality and energy efficiency are enhanced.

In a different approach, researchers have explored a cooperative two-hop device-to-device (D2D) transmission model for vehicle-to-vehicle (V2V) communication to offload substantial amounts of vehicular data from cellular networks to vehicular networks. This study formulates the joint optimization of relay selection, spectrum allocation, and power control from an energy efficiency perspective. A two-stage resource allocation algorithm is proposed, employing an auction-matching strategy to jointly optimize relay selection, spectrum allocation, and power control, maximizing energy efficiency for both two-hop D2D-V2V and cellular links through an iterative process.

Hybrid V2X Communications

The previous sections discussed Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communication scenarios. In the context of the Internet of Vehicles (IoV), communication encompasses not only V2I and V2V but also more advanced interactions, including Vehicle-to-Unmanned Aerial Vehicle (V2U), Vehicle-to-Grid (V2G), Vehicle-to-Cloud (V2C), Vehicle-to-Pedestrian (V2P), and Vehicle-to-Device (V2D) communications. This section highlights energy-efficient hybrid Vehicle-to-Everything (V2X) communication methods that incorporate multiple vehicular communication modes.

IV. RESULT

The proposed methods are evaluated using an M/M/c queuing model. For this evaluation, we assume a 20 MHz bandwidth and an average EV transmission rate of 5 Mbps. We modeled electric cars (2022) with 40 kWh Li-ion batteries. The simulation was conducted in Matlab, taking into account various dynamic factors, such as hourly allocation of charging outlets, hourly demand levels, offered discounts, and the number of served EVs per hour. The implementation provided insights into the operational efficacy of the proposed cloud-based EV charging models.

This description provides an in-depth analysis of the dynamic deployment of edge and remote cloud servers to manage EV (electric vehicle) traffic. Below is a detailed explanation of the concepts and observations in the context of Figures 5, 6, 7, and 8, as well as the CEM (Cost-Efficient Model) approach:

Distribution of Edge and Remote Cloud Servers (Figure 5)

Dynamic Server Allocation: The number of servers—both edge and remote cloud servers—is adjusted dynamically based on traffic volume. This ensures that server deployment aligns with demand patterns, enhancing cost efficiency and system performance.

Off-Peak Hours: During off-peak periods (hours 1–5, 11–13, and 20–24), parking lots observe zero EV traffic, eliminating the need for remote cloud servers. This reduces operational costs as no additional computational resources are required.

Peak Hours: Peak traffic times occur at hours 8, 9, and 16, necessitating the deployment of additional remote cloud servers. This ensures that the average waiting time for EV owners remains within acceptable limits, avoiding delays and ensuring user satisfaction.

Efficiency of Edge Servers: Edge servers are shown to require fewer deployments compared to remote servers. This is due to their higher processing efficiency and their ability to handle balanced hourly arrival patterns, reducing the overall need for large-scale infrastructure.

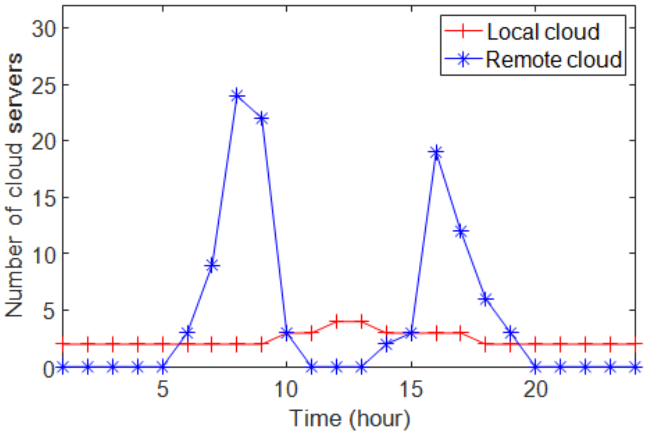

Figure 5. Cloud servers allocation

Performance During Off-Peak Times (Figures 5.2–5.4)

Ample Resource Availability: During off-peak hours (hours 1, 7, 11, 15, 18, and 24), all three scenarios (as shown in Figures 5.2–5.4) indicate similar performance metrics. This can be attributed to the abundant server supply, which easily meets the lower demand.

Performance Metrics: Metrics such as service rates, average waiting times, and energy usage remain consistent, showcasing the efficiency of the allocation strategy during low-demand periods.

Hourly Charging Demand and Load Redistribution

Charging Demand Patterns: The hourly charging demand remains constant across the baseline and CEM models because the number of EV arrivals (as detailed in Table 1) does not change.

Load Redistribution with PIM: During peak hours (8, 9, and 16), when demand exceeds supply, the Peak-Load Incentive Management (PIM) system redistributes part of the charging load to off-peak hours. This is achieved by providing discounts to EV owners for delayed charging, encouraging them to charge during less congested times. Additional Power Procurement in CEM: Under the CEM model, the System Operator (SO) procures additional electricity during peak hours to meet the surge in demand. This ensures that the system remains operational and efficient despite the increased load.

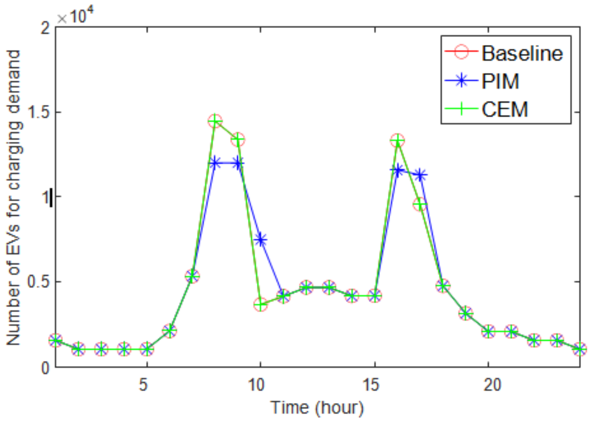

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Figure 6 Charging demand.model

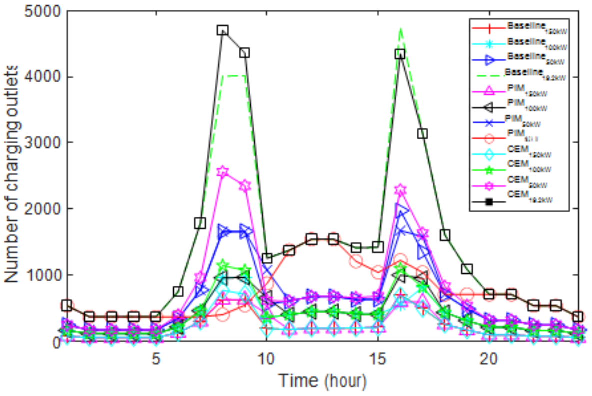

Figure 7. Charging outlets allocation.

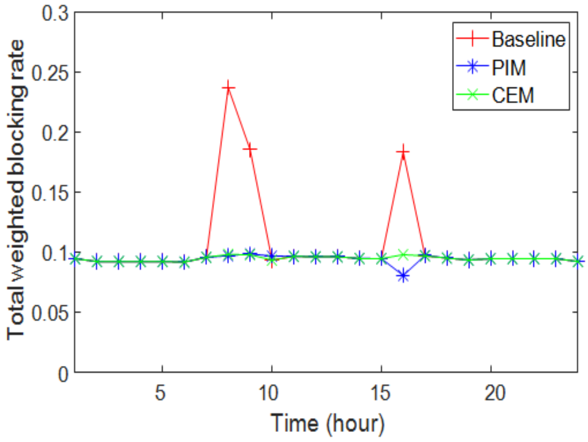

Figure 8. Weighted blocking rate of Model

V. CONCLUSION

This paper comprehensive vision of the Internet of Vehicles (IoV), focusing on cloud-based EV charging management as a practical use case that meets diverse customer service needs through a two-tier cloud infrastructure—comprising edge and remote cloud computing. By accounting for factors like EV arrival patterns, varying communication demands, charging needs at stations, and limited resource availability, we developed a hierarchical model. This model includes cloud server allocation, charging station (CS) capacity planning, and two innovative charging management methods: Peak Incentive Management (PIM) and Cloud Energy Management (CEM).

The proposed architecture offers several advantages. Notably, edge computing's proximity to EVs supports real-time IoV services, while the combined use of edge and cloud resources minimizes computing and communication complexity in an affordable, scalable way. Our findings highlight the model's efficiency, showing a 10.2% increase in system profitability compared to unmanaged scenarios, while maintaining high-quality service for EVs with low blocking rates and minimal cloud server waiting times.

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