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Intelligent Resource Monitoring and Control Method in Vehicular Ad-hoc Networks for Electric Vehicle Enabled Microgrids

Dr. Arasu Raman[1*], Nick Wong Yi Ting[2], Dr. Rajani Balakrishnan[3], Dr. Baskar Sanjeevi[4], and Dr. Vijayesvaran Arumugam[5]

[1*]Faculty of Business and Communications, INTI International University, Malaysia. arasu.raman@newinti.edu.my, https://orcid.org/0000-0002-8281-3210

[2]Faculty of Business and Communications, INTI International University, Malaysia. nick.wongyt@gmail.com, https://orcid.org/0009-0008-4588-5363

[3]Faculty of Business and Communications, INTI International University, Malaysia. rajani.balakrishnan@newinti.edu.my, https://orcid.org/0000-0002-0467-2053

[4]School of Engineering and Technology, Vels Institute of Science, Technology & Advanced Studies, India. baskar133.se@velsuniv.ac.in, https://orcid.org/0000-0002-0810-3755

[5]School of Business and Technology, IMU University, Malaysia. vijayesvaran@imu.edu.my, https://orcid.org/0000-0001-9307-1307

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Abstract

Software-Defined Networks (SDN) and Cloud Radio Access Networks (CRANs) are added to vehicle ad hoc networks (VANETs). The goals include making data transfer and resource sharing more efficient, achieving the shortest possible wait and response times, and ensuring the network is reliable even when conditions change. The usual ways of handling and grouping loads in Electric Vehicles (EVs), which are made for stable environments, need to be changed to work with VANETs, which are constantly evolving. To regularly meet these high service levels, focus on more adaptable and durable solutions. This study shows a software-defined EV fog computing design that improves VANETs' resource sharing. The suggested design uses smart controls placed strategically in the network to make the flow of data and use of resources as efficient as possible. The system uses parallel processing to split up computing tasks among EV stations. This makes the network more mobile and lessens the chance of jams. Simulations and real-world tests of the model show that it makes the network much more efficient. The study found that compared to traditional methods, the average response time went up by 29%, network delay went down by 23%, and it took 27% less time to get to the best assets spread.

Keywords: Resource Monitoring, Electric Vehicle, Vehicular Ad-hoc Networks, Smart Microgrids.

*Corresponding author: Faculty of Business and Communications, INTI International University, Malaysia.

1 Introduction to Electric Vehicle and Resource Monitoring

Electric Vehicles (EVs) are becoming increasingly common, which suggests that they could play a big part in making transportation and energy systems more environmentally friendly in the future (Sanguesa et al., 2021; Mishra & Kumar, 2023). Electric vehicles (EVs) have many qualities, but the most important one is that they can serve Intelligent Transportation Systems (ITS) and the Microgrid (MG) (Dagar et al., 2021). EVs can connect to the MG through Vehicle-to-Grid (V2G) (Bibak & Tekiner-Moğulkoç, 2021). When there isn't enough power, the energy stored in the EV batteries is sent to the MG to meet extra-high needs. The usual way of sending saved power from EV batteries to customers through the MG makes the network less efficient and costs more for energy (Trivedi et al., 2023). EVs that store, move, and provide energy to Critical Loads (CLs) directly make the system more efficient. This leads to lower network loss and lower energy costs. The spectrum needs to be closely controlled so that EVs and MGs can reliably talk to each other through the Base Station (BS). To handle the spread of energy assets across large areas, the system would need specific information about EVs, such as how long their batteries last, how much energy costs, and maps of the region. For V2G interaction to go well, this data must be sent quickly and efficiently over wireless communication lines.

ITS integration is a vital part of building smart city systems. Vehicular ad-hoc networks (VANETs) are essential for ITS because they let EVs and roadside equipment talk to each other (Mchergui et al., 2022; Manipriya et al., 2020). VANETs are known for moving around a lot and making quick changes to their structure, so they need strong and flexible methods to handle communication, distribute resources, and spread out efficient work (Harang & Hyun, 2024). Most traditional methods are set and centralized, so they need to be changed to fit the needs of VANETs as they change. This makes them less effective and less scalable.

For better resource control in VANET, Software-Defined Networks (SDN) and Cloud Radio Access Networks (CRAN) have to get better (Keshari et al., 2021; Pana et al., 2022). With SDN, network assets can be managed more quickly because of the unified control system it offers (Ram & Chakraborty, 2024). CRAN manages it through a cloud-based system. These advancements run into problems because EVs are transferred a lot in wireless networks, making it hard to keep service going and ensure the network is reliable (Park et al., 2019). The study suggests using fog computing methods to get around these problems. By carefully putting managers in charge, this method cuts down on the number of handovers and improves the distribution of resources.

2 Background and Findings

This section outlines the newest improvements to SDN and CRAN that have made it easier to handle resources in VANETs. The main focus is ensuring that Internet of Things (IoT) apps work together correctly, sharing resources and load at the edge, and ensuring people are rewarded for working together to share resources (Kimura & Premachandra, 2016).

New developments have changed how schedule apps for the IoT and big data analytics work (Subrahmanyam et al., 2024). Subrahmanyam et al., described architecture, modelling the environment, optimization, decision motors, and measuring performance with green energy sources (Subrahmanyam et al., 2024). To find out what makes customers want to accept new technology, Raman et al. made an adaptable scheduling system for computing in fog and edge settings that have trouble changing to changes in their environment (Raman & Ramachandaran, 2023). Raman et al., investigated a weighted actor-learner design for making deployment choices in edge situations to provide a delightful customer experience (Raman et al., 2023). Their design requires more sophisticated exploration tactics in mobile settings. Prashanth et al., introduced a cognitive plane design that used cognitive fog resources but faced the problem of allocating too many resources in the logistics industry (Prashanth et al., 2024).

Innovations in distributed Load Balancing (LB) include the work of Ahmad & Mehfuz who developed a latency-centric strategy employing a continuous-time framework and a flexible heuristic technique (Ahmad & Mehfuz, 2024). Enhancing its performance by including different migration rates is necessary. Rehman et al. introduced a data transmission design consisting of four layers for transferring information from EVs to edge devices. This design relies on microservice accessibility control, but its effectiveness depends on controllers' placement and efficient LB. Sebrechts et al., proposed an intent-based architecture (Sebrechts et al., 2022). Conventional virtual approaches exhibit slower execution durations. Zeng et al., proposed a strategy for distributing workloads across edge computers (Zeng et al., 2020). The diversity in processing EV information impacts task allocation.

Li et al., proposed a strategy for distributing resources in fog situations equipped with EVs (Li et al., 2020). Their arbitrary selection of resources results in inefficient distribution. Hussain et al. devised a way to improve working speed (Hussain et al., 2021). EVs could be more efficient because they can't be predicted. Abdullah et al. suggested a different target node to make launching edge Vehicle-To-Everything (V2X) apps more efficient (Abdullah et al., 2021).

Significant improvements have been made to how resources are managed for Vehicular Edge Computing (VEC) and how resources are allocated. Liu et al. created an incentive model to strengthen the part of a VEC service in tasks (Liu et al., 2021). As a result, the computer needed to be more stable and handle more traffic. Ng et al., developed a dual auction method for assigning computer resources for code tasks (Ng et al., 2021). Finding a good balance between repair boundaries and communication costs has been challenging.

These studies bring up problems like how price methods can increase server traffic, how recovery limits must be carefully balanced, and the communication costs when allocating resources. The technique aims to solve these problems by creating the best way to install controllers that adapt to the cost of communication. This ensures that the platform is set correctly and uses resources efficiently.

3 Proposed Resource Monitoring and Control Method

Figure 1 shows a possible form for resource monitoring and control. This physical design allows different parts of EVs and computer tools at various levels to speak to each other without problems.

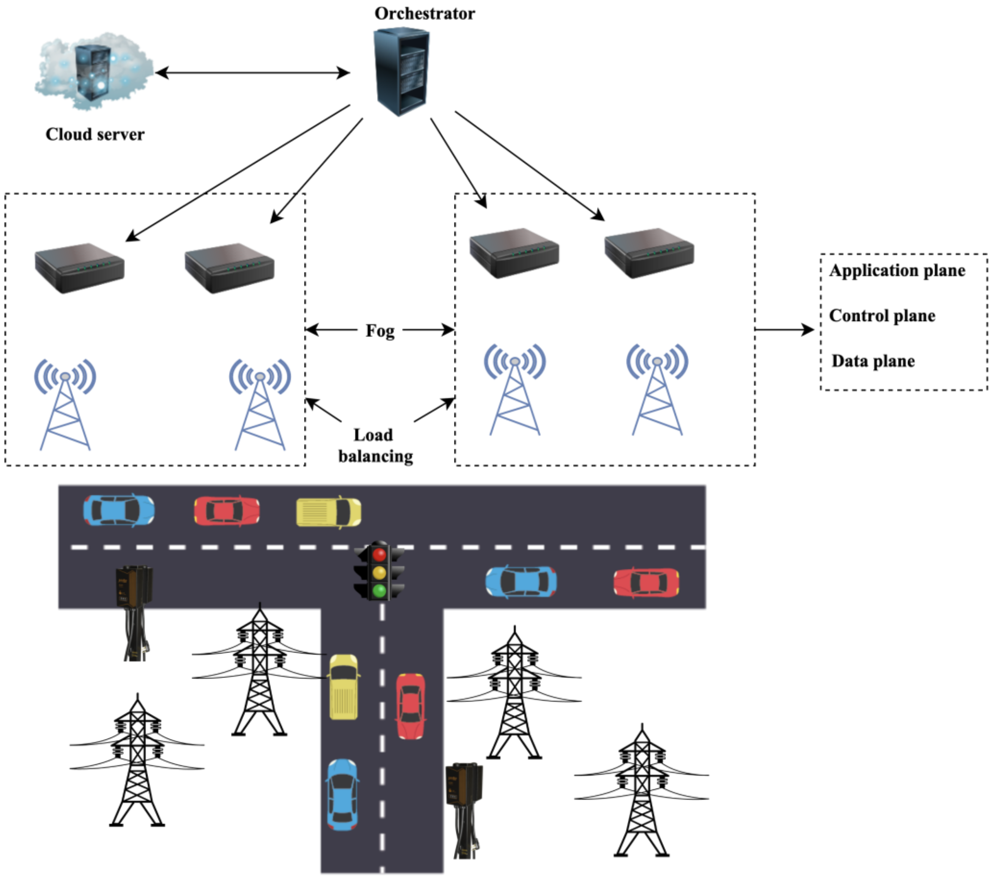

Figure 1: The Architecture of the Proposed System

1) System Model

The system consists of electrical and communication networks. The communication system comprises BS, EVs, CLs, Microgrid Central Controllers (MG-CC), MG, and Smart Meters, as shown in Figure 1. Every EV is linked to a BS by exclusive V2G communication pathways. The wireless connection between EVs and the BS is presumed to be established using the WiMAX protocol. Every CL establishes communication with the BS to collect the current status information about EVs. Essential data necessary for arranging an EV with a CL includes the EV's current location and its projected location, the estimated time required for transportation to the CL, what energy is accessible in the EV for transportation to the CL, the quantity of power that will be set aside for trading purposes and the subsequent transportation of the EV again to its original destination or an appropriate charging facility. The smart meter quantifies power use and can be controlled from a distance, while the MG-CC enables the automatic and synchronized functioning of EVs and CLs. The MG-CC performs various tasks, such as conducting demand reaction operations, optimizing the planning of charging and discharging EVs, and conducting forecasting analyses.

The Cloud Layer consists of a VMware server that supports numerous Virtual Machines (VMs) with powerful multi-core CPUs, high-speed SSDs, and enough RAM. These virtual machines are crucial for managing demanding data processing activities and extensive storage, hence acting as the foundation for sophisticated services in the VANET.

The nodes in the Fog Computing Layer can be thought of as high-performance computing platforms. The flexible network links and high-core CPUs in each router were carefully chosen to ensure that data was processed effectively and sent quickly. Containerization, which creates separate settings for each program, makes people more productive. Docker is used to make this happen. The fog nodes in charge of being cluster managers control communication and divide resources within their clusters. These hubs are necessary to speed up the network and reduce the time it takes to handle data.

EVs with Onboard Units (OBUs) and Roadside Units (RSUs) comprise the Edge Layer. When GPS, V2X wireless transceivers and 4G/5G components are used together, they make it easier for EVs to talk to each other and improve communication in MG. This layer is necessary to get up-to-date information and acts as the network's entry point for feeling and detecting.

Adding an SDN manager to the fog layer makes designing and controlling the network possible. The controller controls what happens on the network, ensuring communication and resources are managed well. When real-time EV happens, the controller's main job is to change the network settings. The cloud layer incorporates a traffic management server that utilizes immediate traffic information from Google Maps to make educated routing choices in MG. The cooperation with the SDN controllers guarantees the best use of network assets and the maintenance of vehicle-to-RSU connection with the lowest delay.

2) Load Balancing Model

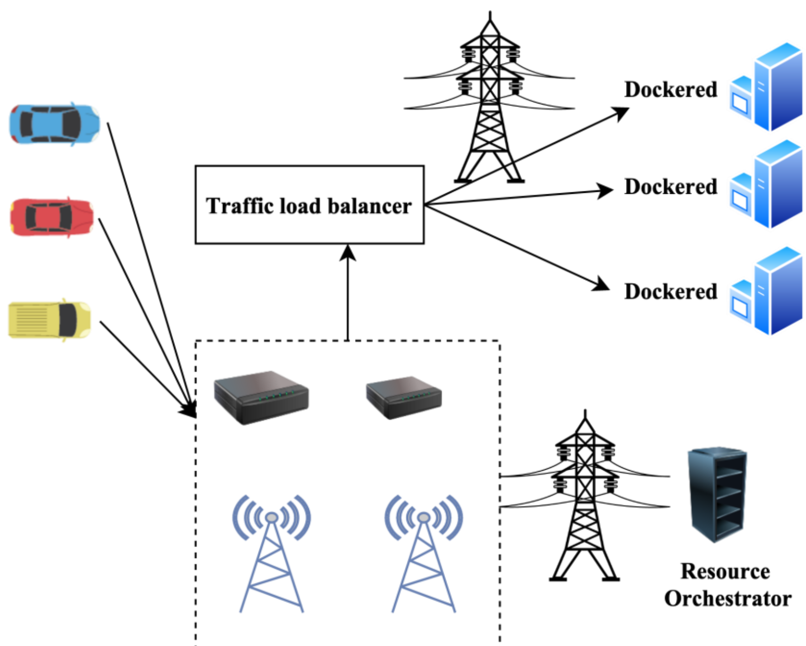

Figure 2: Load Balancing Model

The LB model is shown in Figure 2. The execution of the LB involves the following steps:

Containerization involves encapsulating application elements into separate containers, such as Docker boxes, enabling simple deployment and maintenance.

Service Identification is used as a tool for service discovery, where service ends are added and found.

The LB of traffic is set up inside Traefik, using front-end and back-end principles for LB depending on traffic flow.

A separate front-end is configured for each group, with a specific web address and port numbers assigned to it.

The back-end setup of Traefik involves constantly discovering destinations using service search.

Traefik performs LB by distributing incoming information across data points depending on the flow.

A real-time flow-based LB method is built into the Traefik weight balancer. This approach handles network traffic well by putting information bits into different "flows." These events are put into groups based on things like Internet Protocol (IP) addresses and ports that are similar to all. How well this network works depends on how well it can accurately analyze and spread data, ensuring each flow goes where it needs to go based on its unique needs and features in MG. The network's ability to handle data and communicate more efficiently is improved, which leads to faster responses and a more even spread of network assets. Traefik will constantly watch service ends and judge their health and performance based on how quickly they respond and how much resources they use.

It can work with finding service tools to update the network's current state. So it can quickly make changes to the route configuration.

Service weights are randomly given based on real-time demand and efficiency. This changes how new requests are spread out in MG.

Traefik immediately changes its settings when its speed limits are pushed too far. This makes sure that requests are handled in the most efficient way possible in MG.

The inquiries are reassigned based on the new weights, ensuring the demand is spread fairly across all available capacities in each service instance.

4 Simulation Findings

Researchers test how well the method works using entropy to determine how uniform LB is across all network nodes. The results in Figures 3a and 3b show that MG works better when the work is evenly distributed. The entropy goes from 2.8 to 4.7 as the number of requests goes from 10,000 to 100,000. This shows a clear link between the number of requests and the entropy. This increase indicates that the platform can handle many requests, spread the work out evenly, and keep the platform from being too dependent on a few nodes or problems. Traditional random distribution methods, which only sometimes consider the nodes' current task and ability, cause resources to be used unevenly in MG. The technique combines adaptive clustering with flow-based LB, increasing entropy levels and suggesting a more evenly distributed load over the network.

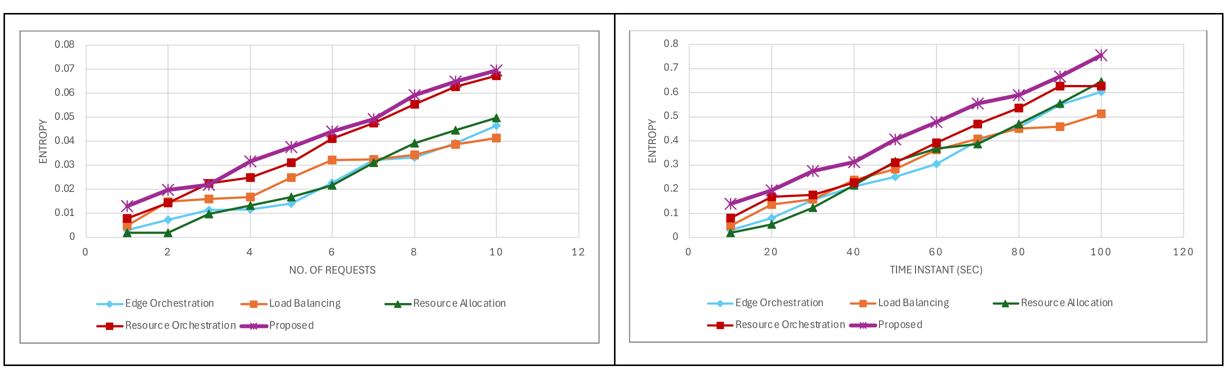

Figure 3a). Entropy vs. Requests Analysis and 3b). Entropy vs. Time Instance Analysis

Figure 4a demonstrates a direct correlation between reaction time and system load, emphasizing the constraints in processing capacities despite the system's efficiency in allocating resources and managing the load in MG. The approach outperforms standard methods, providing fast response times, even in heavy demand. Figure 4b demonstrates how higher network latency leads to longer reaction times, highlighting the delay in transmitting data from the source to the target. The approach addresses this issue by allowing data processing closer to the system's edge in MG. This reduces data travel time, resulting in lower latency and aligning with distributed computation concepts. The effectiveness of the design and cutting-edge algorithms differs.

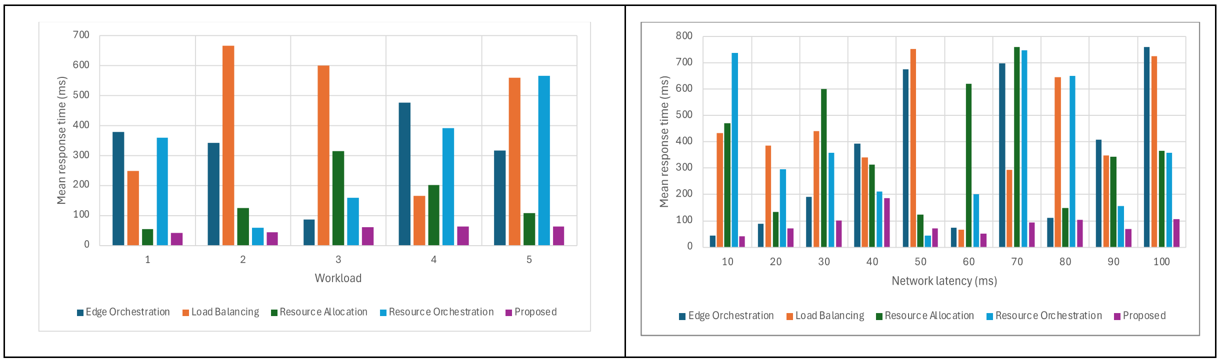

Figure 4a). Mean Response Time vs Workload Analysis and 4b). Mean Response Time vs. Network Latency Analysis

5 Conclusion and Discussion

The study presents a new approach for distributing resources and determining where to position controllers in VANETs. This approach utilizes dynamic grouping and flow-based LB in MG. The architecture guarantees the effective allocation of resources and the control of workload by grouping EVs based on their proximity and communication. Using MapReduce for concurrent processing dramatically decreases the time it takes to reach convergence in MG. By including the Traefik load balancer in the flow-based design, the research ensures that network traffic is evenly distributed across controllers, reducing the danger of overload. System effectiveness is improved by placing controllers, achieved via optimizing integer linear programs. The empirical data confirms the technique's efficacy, demonstrating substantial advancements in VANET administration via improved efficiency, adaptability, and dependability. Although the controller positioning requires significant computer resources, integer programming identifies optimum or nearly ideal solutions in MG. The time difficulty remains a challenge for large networks. Future studies aim to incorporate quantum technology at both cloud and edge layers to enhance processing speeds, possibly leading to a paradigm change in near-instantaneous communications. This investigation seeks to pave the way for a new era of network management designed to meet the requirements of contemporary EV networks and LB.

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Authors Biography

Dr. Arasu Raman, is a senior lecturer in Marketing and Management at INTI International University, holding a Ph.D. in Business Administration with a specialization in Marketing. His international educational background includes degrees from institutions in New Zealand, Australia, and the Philippines, which contribute to his global perspective. With over 27 years of teaching experience, he is certified as a Professional Trained Teacher by the University of Hertfordshire and in Case Teaching by Harvard Business School. Dr. Arasu has published 26 research articles in prestigious journals on topics such as entrepreneurship, digital marketing, and marketing information systems, including Scopus and WOS listed journals. As the university's sole entrepreneurial scientist and an active industry consultant, he is renowned for his innovative curricula and extensive international teaching experience. Dr. Arasu is honoured for his excellence in teaching, research leadership, and collaboration with major multinational companies.

Nick Wong Yi Ting, is the Chief Financial Officer at Setia Media Sdn Bhd, a prominent player in outdoor advertising specializing in digital billboards (DOOH), since July 2024. In this role, he oversees financial strategy, budgeting, and forecasting to drive growth and profitability. Previously, Nick was a Business Development Manager at Spring Capital Management Sdn Bhd, and has held various banking roles, including Preferred Relationship Manager at CIMB Bank Berhad and Senior Financial Service Consultant at Alliance Bank Malaysia Berhad. He holds an MBA from INTI International University and a BSc in Architectural Studies from LIMKOKWING University, with multiple financial certifications including RFP and FIMM.

Dr. Rajani Balakrishnan, holds a Ph.D. in Mobile Technology and brings over 20 years of teaching experience in higher learning institutions. Her expertise lies in integrating cutting-edge mobile technologies into educational settings, enhancing learning outcomes for students. Dr. Balakrishnan has been instrumental in shaping curricula that bridge the gap between technology and education, fostering innovation in the classroom. Her dedication to academic excellence and her passion for teaching have earned her recognition as a leader in educational technology. Throughout her career, she has mentored countless students, guiding them toward success in the digital age.

Dr.S. Baskar, completed his B.E. in Mechanical Engineering from M. Kumarasamy College of Engineering in 2010 and his M.E. in Refrigeration and Air Conditioning from Anna University in 2012. He has been an Assistant Professor at Vels Institute of Science, Technology and Advanced Studies since 2017, with over 10 years of teaching experience and a track record of guiding numerous student projects. Dr. Baskar has published over 50 research papers, attended 47 workshops, and presented at 40 conferences. He is a reviewer for various reputed journals and holds five memberships and awards.

Dr. Vijayesvaran Arumugam, is an academician at School of Business and Technology, IMU University (Formerly known as International Medical University). Dr. Vijayesvaran Arumugam obtained his doctoral degree in International Marketing from School of Management, University Sains Malaysia. His Field of interest includes international marketing, marketing, e-marketing, e-business and management.