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Blockchain-Driven Framework for Enhancing Electric Vehicle Performance and Internet of Vehicle Connectivity

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Abstract: Internet of vehicle (IoV) is a new way of enhancing vehicle performance and communication. This paper investigates the technology and applications that drive its integration. By dealing with data privacy, speed, and sizing issues, IoV in electric vehicles enhances real-time data transfer, predictive maintenance and route optimisation. The research led to the Blockchain Six-Layer Centralised Architecture Model (BS-LCAM). This research mainly seeks to improve the efficiency and safety of electric vehicles (EVs) and IoV networks. The six levels comprising this paradigm are data link, physical, transport, application and security. For instance, this layer assures that information can be kept safe over networks but cannot get lost or modified without all parties' permission. All these stages are enhanced by blockchain technology. It provides a secure connection for the BS-LCAM framework, allowing fast data storage and seamless interoperability among several IoV constituents. For example, an intelligent mobility system's flexibility (comprehensive BS-LCAM model) might benefit different areas such as autonomous driving, energy optimization, fleet management and user-centric services. This paper simulates the performance of BS-LCAM model in diverse environments with 97.6 % performance and scalability, 98.7% route optimization and route optimization.

Introduction

Integrating IoV has led to improved performance of electric vehicles and their connectivity, thereby changing the industry technologically (Kapassa et al., 2021). Such interconnectivity can change how electric cars operate in their environment. To connect infrastructure, people, and cars, modern means of communication like 5G technologies used Vehicle to Everything (V2X) and edge computing (Abro et al., 2023). It improves energy efficiency by providing real-time diagnostics and supports for EVs (Chen et al., 2021). Thus, making it more reliable and extending its life span. Navigation systems have become so sophisticated, according to IoV that they offer the most reactive traffic information when compared to others (Aldhanhani et al., 2024). Time spent travelling reduces and productivity increases(Singh et al., 2024). Autonomous driving is made possible by continuous data sharing with reduced latency, this ensures the dependability and safety of autonomous vehicles (Mahmood, 2020). By streamlining information and entertainment while enabling personalisation, IoV enhances the user experience (Li et al., 2023). "Smart charging infrastructures" can benefit from the IoV. Electric vehicles can be plugged into charging stations to facilitate off-peak charging and load control (Islam et al., 2023). Balanced grids are economical. Through route optimisation (Alqahtani et al., 2024), vehicle monitoring, and maintenance scheduling (Ullah et al., 2023), the IoV enhances the efficiency (Yuvaraj et al., 2024) of fleet management (Arooj et al., 2022). Connectivity between infrastructure and vehicles (V2I) and vehicles and pedestrians (V2P) through the IoV enhances traffic management and road safety, enabling smart cities to flourish (Storck and Duarte-Figueiredo, 2020). Electric and networked vehicles work together to reduce pollution and increase efficiency, which speeds up technical advancements (Duan et al., 2020). Therefore, for the automotive sector to become more connected, efficient,

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and environmentally friendly, electric vehicles must be integrated with IoV (Wu et al., 2023).

While the IoV has the potential to enhance the connectivity and performance of EVs, a few issues must be addressed before this can happen. Some of these challenges include issues with trustworthy communication networks, data privacy, and cybersecurity (Kim, S et al., 2020). Data and vehicles are vulnerable to hackers who get access to linked vehicles, making cybersecurity a top priority (Taslimasa et al., 2023). As a defence against these dangers, companies employ robust encryption, secure connection protocols, and round-the-clock monitoring (Reddy and Reddy, 2024). Additionally, robust data protection laws are necessary to address the critical issue of user data security. That is of paramount importance in terms of user data security and openness. For the Internet of Vehicles (Emodi et al., 2023) to function smoothly, it is essential to construct infrastructure that utilises fast, low-latency communication networks, such as 5G (Jayakumar and Peddakrishna, 2024). Massive expenditures in infrastructure, tech-automotive alliances, and continuous research and development to innovate and improve security are necessary to address these concerns. A safe connection will exist between EVs and the IoV (Hasan et al., 2023). The major contributions of this article are,

- IoV technologies and integrating them into the system can improve the overall performance and connectivity of electric vehicles. For route optimisation, predictive maintenance, and real-time data sharing have thus been laid down.
- Establishing and evaluating the BS-LCAM for Improving Reliability, Performance and Compatibility of Global Vehicle Networks Involving EVs with Blockchain Technique.
- Smart mobility created by the extensive BS-LCAM framework is capable of advancing intelligent mobility that could result in gains in different areas like autonomous driving, energy optimization, fleet management and user-centric services.

The following is an outline for the final section of the research paper: Section II explains the literature survey. Section III explains the Blockchain Six-Layer Centralised Architecture Model (BS-LCAM). Section IV provides an all-inclusive evaluation, discussing everything from impacts to making links to prior efforts. The findings are presented in Section V.

Related Works

Several innovative approaches have emerged with the advent of smart transportation systems and EV networks. Improved system performance, efficiency, and usability are the goals of these methods. The technique that was developed by (Rimal et al., 2022), which is a cloud-based electric vehicle charging framework (C-EVCF) with cost reductions and an increase in the electricity supply, enhances the system performance and quality of service (QoS) for electric vehicle consumers during peak hours.

Evaluation of energy-efficient techniques (E-EA) in communication, computation, traffic, electric vehicles, and energy harvesting inside 6G networks is included in the suggested method, which was developed by Wang et al. (2022). The results highlight a focus on optimised energy management and developing technologies for environmentally friendly IoV systems.

The method that was developed by Ji et al. (2020) designs a new network architecture (NNA) for IoV, with the primary areas of emphasis being increased data throughput, decreased latency, increased security, and huge connection. In addition to a full literature evaluation, the outcomes include an improved IoV framework.

A cloud-based network model (C-bNM), big data analytics, and security systems are all components of the proposed technique by Qureshi et al. (2021). The proposed method incorporates a six-layered architecture. A complete assessment, novel models, and insights into issues and future directions for IoV are provided by the outcomes through their presentation.

A fuzzy mean clustering algorithm (FCM) that has been improved is used in the proposed method by Qiao et al. (2021) to conduct big data analysis in electric vehicle networks. As a result, there will be fewer delays in the transfer of data and more efficient management of congestion and route direction. The BS-LCAM is one of the most effective of these approaches. The best option for growing EV networks and IoV systems, it offers strong security, productive data management, and smooth interoperability.

The author proposes an intelligent blockchain-based authentication scheme that protects users' privacy (Chen et al., 2024). Ensuring data storage and transaction verification procedures are secure and reliable, this protocol additionally preserves privacy features like user anonymity and untraceability. Furthermore, every node in the network keeps its own copy of the data and uses consensus techniques to confirm its authenticity and integrity, making use of the distributed nature of the blockchain. Verification using the real-oracle random (ROR) model shows both efficacy and security. Informal analysis further confirms robustness against known attacks.

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Smart cities and transportation systems represent just two of the many areas that have shown considerable interest in federated learning (FL) (Rani et al., 2023). There has been limited growth in FL-enabled attack detection for IoVs. Nevertheless, interdisciplinary study is necessary to identify the primary obstacles to implementation in real-world environments. The efficacy of the suggested FL framework is assessed using performance indicators. When examined, the suggested FL method identified attacks in IOV networks with a sensitivity level of up to 99.72%.

A novel electric vehicle battery management system (BMS) was presented in this paper (Afzal et al., 2023). After our proposed BMS was installed, a 100-kilowatt-hour lithium-ion battery pack was successfully tested. The findings reveal an astonishing 15% improvement in total energy efficiency when contrasted with conventional BMS systems. An additional 20% improvement in battery life was a consequence of the adaptive virtual admission mechanism. The substantial improvements in energy efficiency and battery life showcase the effectiveness and excellence of our BMS compared to other systems.

By using next-generation IoV technologies like 5G-enabled V2X communication and AI-powered predictive analytics, this research intends to circumvent these constraints. Secure data interchange between EVs and IoV platforms is prioritized in the proposed framework, which emphasizes strengthened cybersecurity measures using blockchain. In addition, it ensures real-time analytics even in crowded networks by using decentralized edge computing, which tackles scalability concerns. These enhancements are expected to close the performance gaps in previous research and establish the long-term IoV-EV ecosystem viability stage.

Proposed Method

The combination of EVs with the IoV is a huge step towards intelligent transportation infrastructures. The idea behind this is to make cars safer, faster and more connected in terms of technology.

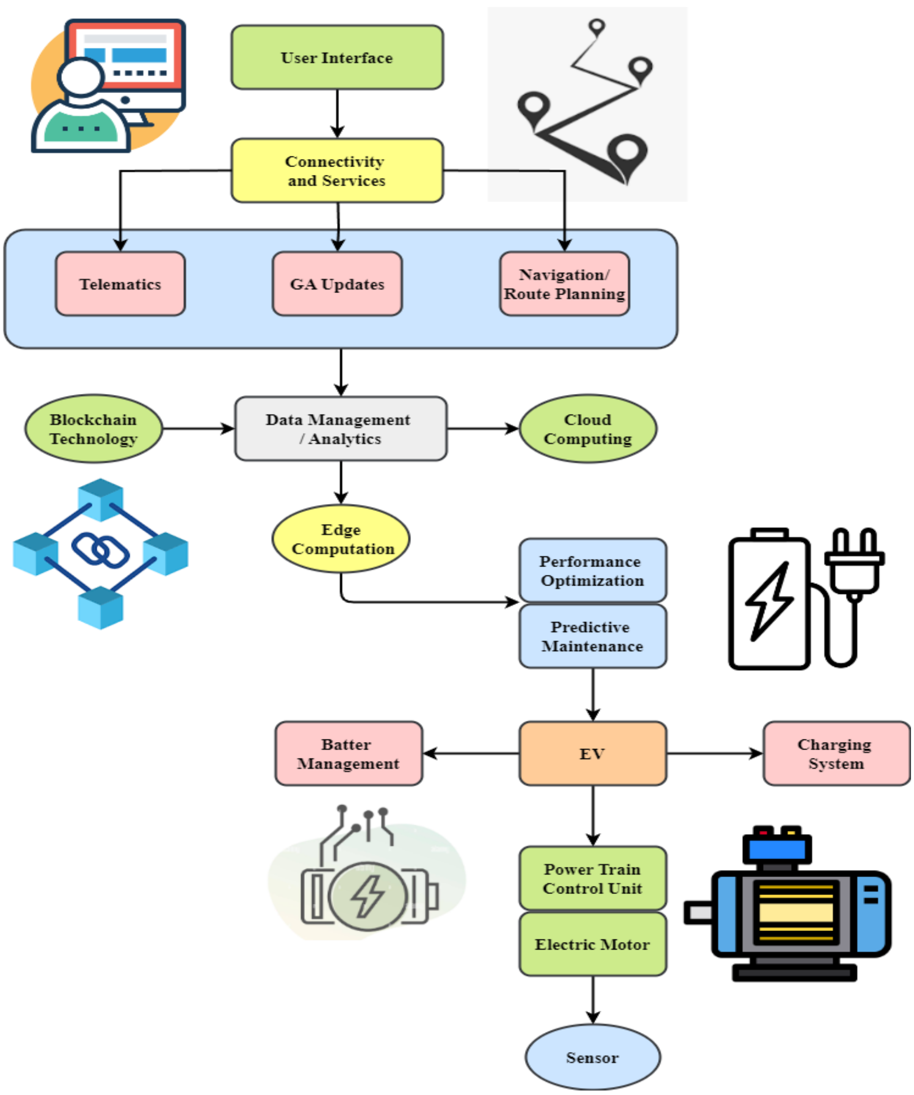

Figure 1. Efficient and Versatile Framework for Electric Vehicles' Interconnection and Performance.

The recommended technology, commonly called BS-LCAM, can address several issues like real-time data transmission, predictive maintenance and improved efficiency in managing routes. To increase communication interconnectivity, security, and affordability in battery-operated automobile networks, Blockchain distributed database technology is employed by BS-LCAM infrastructures. This is accomplished via the utilization of the Blockchain.

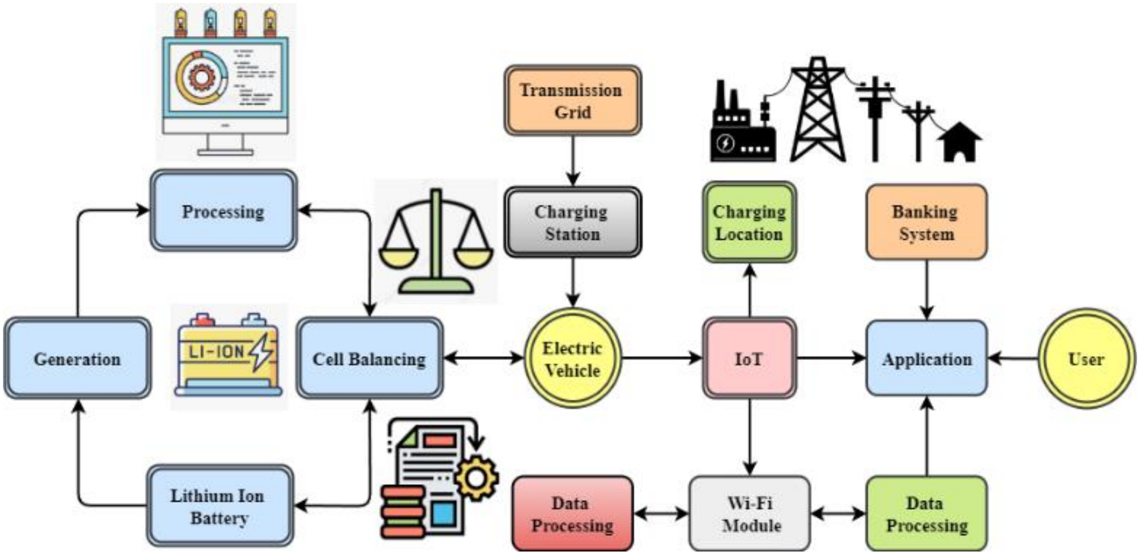

Figure 2. Diagram depicting the components of an EV battery management system.

A multi-layered architecture is shown in this picture, which illustrates ways EVs have improved in terms of both their efficiency and their connectivity. The top-level user experience gives users the opportunity to engage in interactions with the system at large. It facilitates real-time data transfer, software upgrades, and route management via its connection to connectivity and services, which include telematics, over-the-air updates, navigation, and route planning in Figure 1. The use of edges and the Internet of Things are data management and analytics components. Data travels to these areas. In contrast to cloud computing, which processes massive datasets for detailed analysis, edge computing analyses data locally for quick insights. Optimizing performance and predictive maintenance take advantage of the information gained. The electric vehicle's charging framework, the electrical motor, the powertrain controller unit, and battery administration are all areas that Performance Tuning aims to improve. With the help of sensors and onboard diagnostics (OBD), these parts work together to provide real-time diagnostic and performance data. Improving the EV experience and operating effectiveness, this framework guarantees successful operation, immediate revisions, and planned upkeep.

$$v_{pp} + \forall\propto^2 q = \partial_w p - \beta k_{dw} + g\big(v(c,s,d)\big) \quad (1)$$

Several variables impacting the EV-IoV system's connection and performance interact with one another, as shown in Equation 1. In this case, v_{pp} is the main variable representing the performance of the vehicle, $\forall\propto^2 q$ is a term that considers connection variables, $\partial_w p$ is related to the change in efficiency metrics, βk_{dw} deals with latency impacts, and $g\big(v(c,s,d)\big)$ is a function that includes factors such as connectivity, safety, and data honesty.

$$e_{vf}(z-pk) = w_{qq}(p,w,q) + z \times (-m,m), \;\; u \leq \forall \quad (2)$$

Equation 2 demonstrates the way several variables affect the efficiency of electric vehicles (e_{vf}). This is where $z - pk$ shows the modified effectiveness variables, $w_{qq}(p,w,q)$ shows the combined impact of efficiency, interaction, and security measurements, and $z \times (-m,m)$ adds an adjustment factor that takes possible variability into account. The system is limited to operational constraints by inequality $u \leq \forall$, which highlights the BS-LCAM model's capacity to maximize effectiveness.

Figure 2 depicts the suggested system design. It has a charging mechanism, a photovoltaic (PV) panel, a planned battery management system, and an app that connects to the Internet of things. When exposed to sunshine, the PV panel produces direct current voltages and sends them to the power grid. Electric car charging stations and controllers, as seen in Figure 2, charge the vehicle's Lithium-ion battery. A battery must first maintain energy before the PV source can function. Since PV is not as efficient as fossil fuels, it needs to be stored when the sun doesn't shine. Therefore, it will be utilized when stored in the battery when needed. The BMS's principal role in EVs is to monitor key metrics such as battery life, charging cycles, capability, voltage,

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temperatures, state of the driver's seat consumption of electricity, remaining runtime, and operating time. Using a specialized user interface, the created system may provide electric vehicle owners with up-to-the-minute details on the closest charging station that offers the most efficient and cost-effective charging options and a safe online method for viewing the EV's current battery status.

$$z_{er}(y, \pm m, u) = (3 - \forall) + s_{wq}(y, \pm m, p), \quad \complement \equiv pk(1 + m) \tag{3}$$

System characteristics and error resistance (z_{er}) are described in detail by equation 3. In this context, y stands for a performance-related system variable, $3 - \forall$ suggests possible fluctuation m, and u is a limit or restriction that is operational. While $s_{wq}(y, \pm m, p)$ includes the impact of system reliability, efficiency, and interaction. By excluding certain configurations, the model improves system performance and robustness inside the BS-LCAM structure as guaranteed by the constraint $\complement \equiv pk(1 + m)$.

$$Fw_{xp} + \partial m_{n-1} = (1, u) - W_{e1}(m, pk) = 0, \; u \leq 0 \tag{4}$$

A system's restrictions and force vectors are both shown in equation 4. In this case, the operational vector is represented by $(1, u)$ and terms influencing performance, $Fw_{xp} + \partial m_{n-1}$ and $W_{e1}(m, pk)$ respectively. The BS-LCAM architecture guarantees optimum security and performance by balancing these elements with equality 0, where $u \leq 0$, indicating that the machine is kept within limitations on connectivity enhancement analysis.

A network of communication is an essential component of the future digital counterpart for electromobility, distinguishing it from digital models, digital shadows, and physical models concerning the three types of communication: one-way, between physical models, and two-way, between digital models and physical models. Because of developments in the Internet of Things (IoT), artificial intelligence (AI), and big data, the digital twin idea will be able to provide end users and service providers with real-time information and solutions in the electromobility arena. Figure 3 shows the three levels that make up model of the electric car system's architecture: the physical, telecommunication network, and virtual layers. Physical layer entities, virtual layer representations, and communication network connections between the virtual and physical layers produce big data, products, and services; the concrete layer itself is the major entity.

$$m_{uu}(j, w, q) - \forall^2 p\,(p, k, j) = h\,(f, z, t - u) \tag{5}$$

Various system factors interact with one another and affect efficiency in the way described by Equation 5. The expression $m_{uu}(j, w, q)$ pertains to system metrics that include variables j, w, q, and $\forall^2 p\,(p, k, j)$ accounts for the effects of performance and connection. The function captures the impact of variables on the cumulative behavior of the system $h\,(f, z, t - u)$ for performance importance analysis.

$$\partial_{uk}(y, z) \equiv \forall, u \leq u, \quad u = (R - pk) + (gp - 1) \tag{6}$$

The connection between system modifications and restrictions is shown by equation 6. The rate of alteration of parameters of performance y, z concerning specific variables is represented by ∂_{uk}, wherein $\forall$ it stands for a constant or baseline number. The system can only function within certain bounds, as guaranteed by the

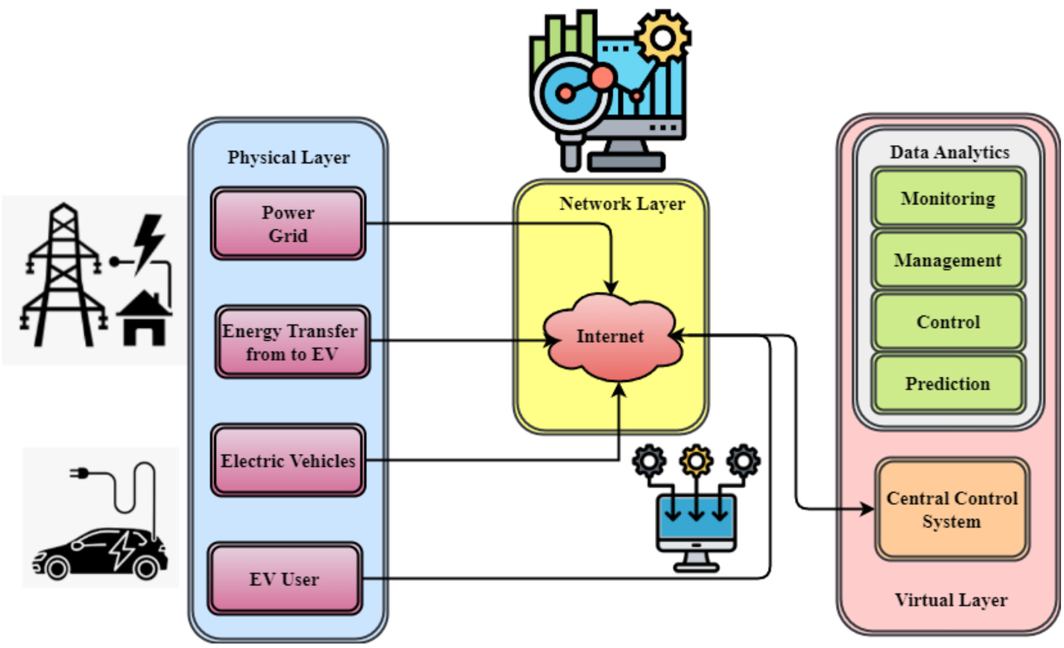

Figure 3. Electromobility general architectural model based on smart grid technologies.

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inequality $u \leq u$. The disparities between assets of the system define the operational range $(R - pk)$ and critical metrics adjustments $(gp - 1)$ on predictive maintenance analysis.

addressable areas within networked devices, linking them and an efficient way for data transfer, making effective cooperation possible considering that mobility between these ends occurs at instances where there can be

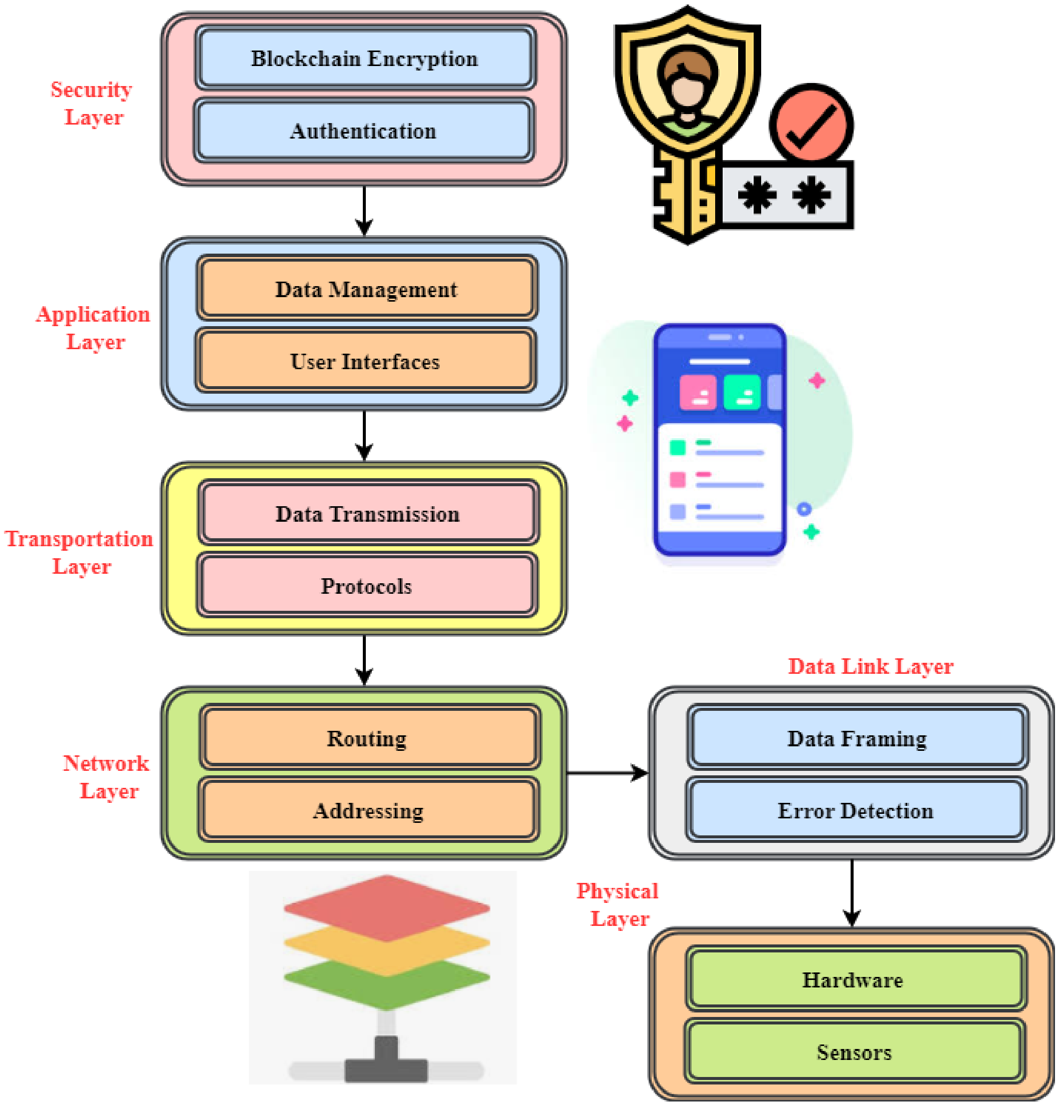

Figure 4. Security for Networks and Data in a Layered Architecture.

A thorough layered architecture for data and network security is shown in this diagram, which is designed to guarantee effective and reliable data management. The actual layer known as hardware, including sensors and actuators interacting with reality, constitutes the lowest level of structures. This layer delivers raw data through a network as shown in Figure 4, forming a base on which all succeeding communicative actions are built.

It takes care of error detection and data organization right above it i.e., knowledge connectivity layer. This will ensure that devices communicate accurate data amongst themselves without any form of wrong information being transmitted among them. To do that, it checks for mistakes and compacts content into panels. Routing instructions and addressing are controlled by this layer known as the shipping layer which acts as well as performs network control function. It manages multiple paths. Lastly, the transport layer concerns itself with ensuring reliable information delivery using existing rules set for datum transmission methods involved since session management features ensure its confidentiality cannot be compromised throughout transfers from one device to another.

At the topmost level of the system design and development stage controls each part of information and user interface changes occur through it all. Moreover, this level links applications or services needed for many different purposes by providing important details required by them. This layer is the point of contact between end-users and the system.

The security layer is the one that is placed on top of all of the layers that came before it and incorporates contemporary safety measures such as authentication procedures and blockchain encryption. This layer is vital

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because it ensures that all activities and communication throughout the network's entire architecture are carried out in a secure manner, which is necessary for maintaining the confidentiality of the information and the confidentiality of the data. The purpose of this multi-layered approach is to improve both efficiency and information security. It does this by providing a standard framework for protecting and handling the information of complex network systems.

$$\propto^u = \propto^{v-1} (v, b, n) - \propto^{v-1} (mku^{v-1}) + h\,(t-1)p \quad (7)$$

The BS-LCAM framework's iterative parameter modification is related to Equation 7. The requirements are defined, $\propto^u$ through which parameters are revised $\propto^{v-1}$ denoting variables, iterator parameters (v, b, n). The term is defined through the accounting of limitation with the vital aspects $\propto^{v-1}(mku^{v-1})$. For route optimization analysis time factors are determined through the performance with further charge defined through $h\,(t-1)p$.

$$v(1, z, p) = z_{qq}(1, p, z-1),\ (z, pk) - S^{+}(\partial \propto +1) \quad (8)$$

The relationship between system adjustments and performance measures is shown in Equation 8. A performance variable $v(1, z, p)$ is affected by the effect of factors on performance, which is captured by $z_{qq}(1, p, z-1)$. The phrase (z, pk) modifies important metrics, and $S^{+}(\partial \propto +1)$ modifies other parameters according to changes in the system and performance factors for scalability analysis.

Results and Discussion

Connectivity, performance, and efficiency may all take a huge leap forward if EVs and the IoV were to

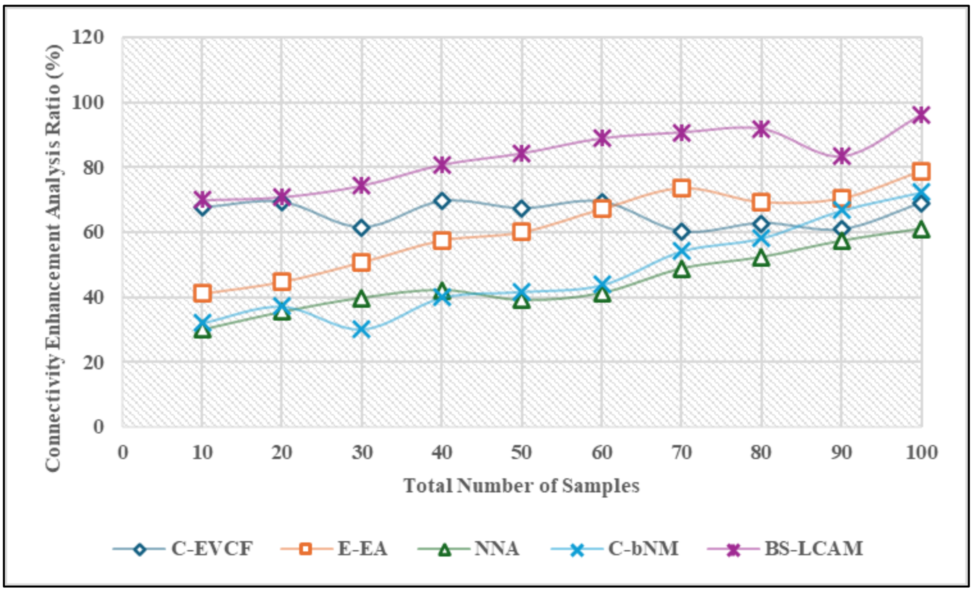

Figure 5. Connectivity Enhancement Analysis.

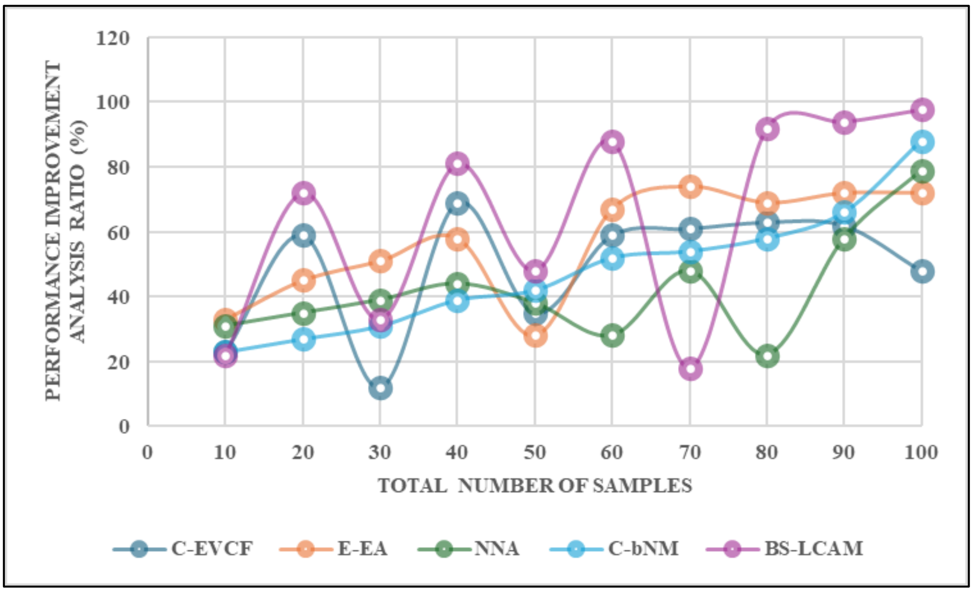

Figure 6. Performance Improvement Analysis.

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integrate. Each study evaluates the role that IoV technologies like 5G, V2X, edge computing, and blockchain play in EV network optimisation, with the goal of addressing critical issues like data security, latency, and network scalability.

Dataset description

Features impacting vehicle collisions on the Internet of Vehicles were included in this dataset (Aldhanhani, T. 2023) Researchers may use it to build an intelligent algorithm-based collision detection warning system or do any other appropriate examination inside the IoV framework.

From the above Figure 5, EVs are unable to communicate with the IoV effectively without a better network connection. The IoV enables EVs, infrastructure, and people to exchange data effortlessly and in real-time through 5G, V2X, and edge computing. Through this connection, state-of-the-art navigation systems can save time and energy by adapting to traffic situations as they happen. Vehicle dependability and lifespan are enhanced through predictive maintenance, which is made possible by continuous monitoring and diagnostics producing 96.2%. Other ways in which IoV enhances user experience include personal infotainment and over-the-air upgrades. This ensures that automobiles always have the most recent software and security upgrades installed. The benefits cannot be exploited unless data security, latency, and network scalability challenges are resolved. Combining IoV with EVs has the potential to improve the safety, efficiency, and use of transportation networks. Data security can be achieved using blockchain technology and proper cybersecurity measures.

The IoV and EVs have the potential to revolutionise EV dependability and efficiency. As seen in figure 6, real-time data flow and analytics enable predictive maintenance, improving vehicle dependability and downtime. This integration lets vehicles adapt power consumption based on real-time data and projected algorithmic operations. Electric vehicles can respond quickly to changing traffic circumstances using the Internet of Vehicles and route optimisation, lowering fuel usage and environmental effects by 97.6%, on-demand updates from IoV eliminate the need for service appearances. By merging 5G and blockchain, IoV integration addresses EV scalability, data security, and latency. It is anticipated that this would result in public transit networks that are superior, more dependable, and more intelligent.

From the above Figure 7, the IoV enables predictive maintenance systems to track the condition and functionality of electric vehicle components through features including real-time data collection and robust analytics. Problem prevention allows us to extend the life of vehicle components and decrease the occurrence of unanticipated failures. The vehicle's sensors document everything from the state of the battery to the operation of the motors and overall system performance produces 98.7%. The data is analysed using machine learning algorithms to determine the optimal maintenance windows, which maximise service schedules and minimise downtime. Estimating the requirement for parts is another function of predictive maintenance, which complements inventory management. Blockchain

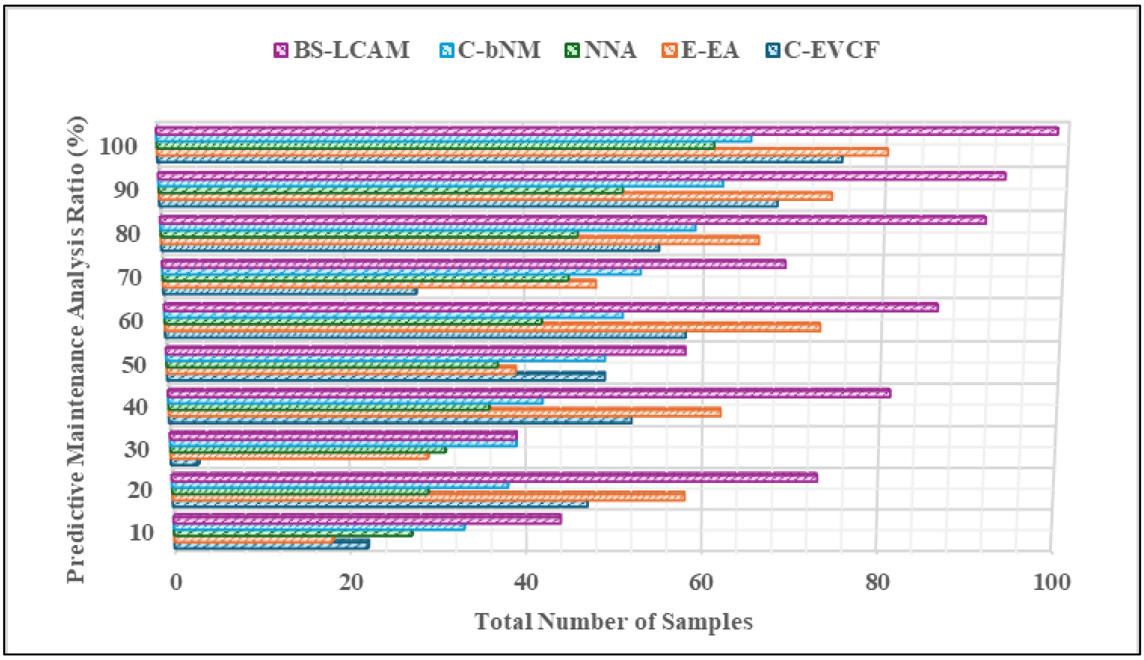

Figure 7. Predictive Maintenance Analysis.

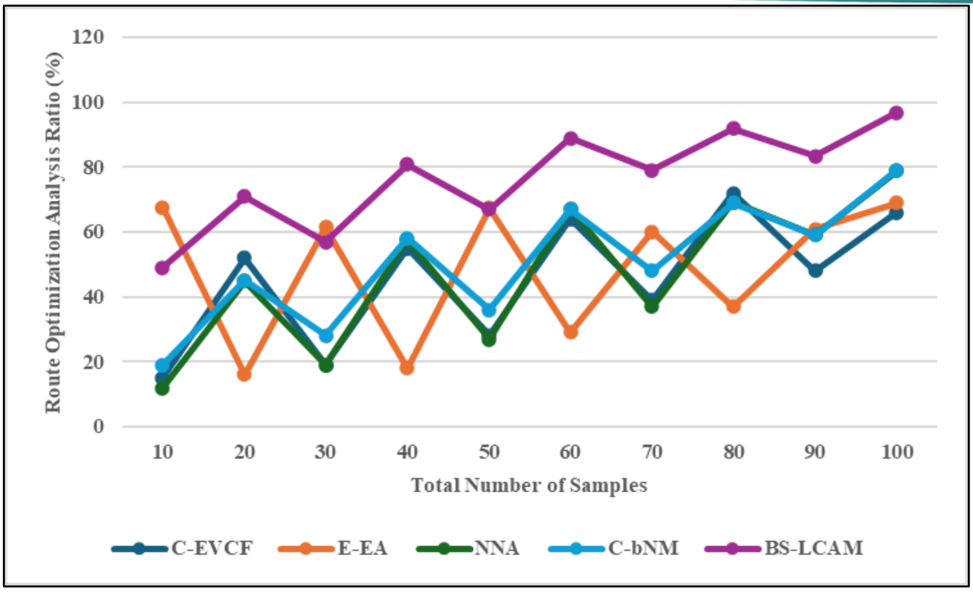

Figure 8. Route Optimization Analysis.

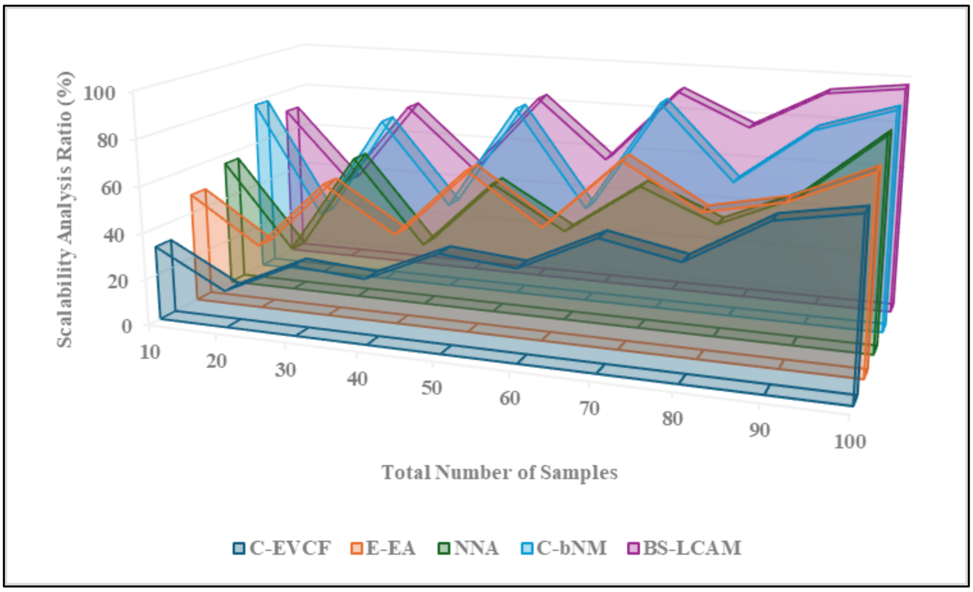

Figure 9. Scalability Analysis.

technology solves problems with data privacy and integrity by making data administration transparent and safe. Safety, efficiency, and electric vehicle dependability could all be enhanced with IoV-based predictive maintenance.

From the above Figure 8, because of the IoT, autonomous electric vehicles may optimise their routes in real-time based on information such as traffic situations, road conditions, and weather predictions. State-of-the-art algorithms can analyse this data to find the most efficient routes, drastically reducing energy and time consumption by 98.7%. By avoiding traffic and other delays, customers can enjoy better driving conditions and get more mileage out of their electric vehicles' limited battery packs. As an added advantage, route optimisation helps the environment by decreasing emissions caused by idling and starting and stopping. Electric vehicles can make quick adjustments because of the Internet of Things' real-time data exchange. When designing smarter, more efficient, and eco-friendly transportation systems, optimising routes with IoV is crucial.

From the above Figure 9, efficient management of data generated by an ever-growing fleet of connected vehicles necessitates scalable integration of EVs and the Internet of Vehicles. As the number of EVs using the IoV continues to rise, the network will need to handle massive amounts of data from all of them without slowing down. Cloud and edge computing must be adopted because of their ability to store massive amounts of data and distribute processing demands. Blockchain technology's decentralisation, data security, and scalability are all enhanced, producing 97.6%. Eliminates inefficiencies in the system. The capacity and low-latency connectivity of 5G networks allows for linking several vehicles. The smooth connection of the Internet of Vehicles is crucial to its scalability. The IoV can facilitate the increased

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adoption of electric vehicles. Doing accordingly will guarantee transportation networks that are strong, efficient, and resistant to disruptions.

Considering these evaluations, the BS-LCAM emerges as the optimal solution. It provides future electric vehicle-interoperability systems with better data management, interoperability, and security.

Conclusion

The utilisation of Internet of Vehicles technology by electric vehicles contributes to the development of intelligent transportation networks. Predictive maintenance, route optimisation, and real-time data sharing are three areas where this in-depth investigation found the IoV to have the revolutionary potential for electric vehicle connectivity and efficiency. The BS-LCAM addresses data security, latency, and scalability concerns in EV and IoV networks. Data, privacy, and traceability are all strengthened at every level of BS-LCAM by the use of blockchain technology. This is made feasible by the six layers physical, data connection, network, transport, application, and security. BS-LCAM's instantaneous data storage, secure transmission, and smooth interoperability appeal to many Internet of Vehicles components. This strategy could improve and secure the transportation ecosystem by advancing autonomous driving, energy optimisation, fleet management, and user-centric services. Numerous simulations suggest that the BS-LCAM model could improve electric vehicle-interconnected vehicle system safety and efficiency. The present research shows that combining IoV and EVs may benefit smart transportation. Sustainability and smart cities may lead to a more environmentally friendly, productive, and interconnected vehicle sector due to the BS-LCAM model's adaptive and durable design.

Conflicts of Interest

None

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