International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Smart Transportation Systems: IoT-Enabled Traffic Management & Vehicle-to-Infrastructure Communication

Ajay Prasad Nautiyal[1], Neha Bathla[2]

[1] Research Scholar, Computer Science Engineering, YIET, Kurukshetra University
[2]Assistant Professor, Computer Science Engineering, YIET, Kurukshetra University

Abstract

Recently, there has been a substantial increase in the number of cars on the road. Escalating traffic congestion is a widespread problem that folks face on a daily basis. The manual control of traffic-by-traffic police has shown to be ineffective. “Furthermore, the signal's set duration has failed to effectively address this issue, regardless of the level of traffic congestion. This research presents a communication system called Vehicle-to-Blockchain (V2B), which utilizes blockchain technology to enable transparent and decentralized communications. The aim is to optimize the incorporation of blockchain technology into V2X (Vehicle-to-Everything) and IoT (Internet of Things) systems, therefore enhancing the efficiency and effectiveness of future transportation systems. We present a range of advanced applications for blockchain technology, such as a car ownership system that utilizes the multi-token standard, a vehicle grading system, the integration of blockchain with the Internet of Things (IoT), and a decentralized ticket administration system for transportation services. The design places a high emphasis on essential elements such as the seamless integration of data, precise precision, and the establishment of secure connections. Furthermore, it includes a decentralized payment system and marketplace for transportation inside smart cities. Our main focus is on the technical execution of smart contracts in these particular scenarios, highlighting their importance in guaranteeing strong and dependable interactions. Our decentralized approach creates a transportation ecosystem that has the ability to adjust and fulfill the evolving requirements of intelligent urban areas. It is groundbreaking, durable, and capable.

Keywords: Transportation, IoT, Traffic, V2I, STS, Infrastructure, V2V, Communication

1. Introduction

The escalating urbanization phenomenon is a complex worldwide issue that demands a comprehensive solution. The urban population has grown as a result of increasing migration to cities. According to the United Nations, the global urban population is expected to reach around 4.9 billion by the year 2030. This gives rise to several concerns, including pollution, transportation congestion, resource depletion, and so on[1]. The proliferation of Internet of Things (IoT) has led to a vast array of interconnected IoT devices. These devices consistently gather data and send it to computer nodes for further processing [2]. Due to significant progress in deep learning techniques, several applications use deep learning to analyze collected data and achieve "intelligence" and "automation". As a result of data analysis and the use of

IoT infrastructures, "Smart Cities" have become more popular. These cities include many applications such as smart grids, smart transportation, smart manufacturing, smart buildings, and other related fields [3,4]. Transportation systems are vital elements of individuals' daily lives. As urban population increases, there will be a substantial increase in motor vehicles globally, resulting in adverse effects such as traffic congestion, noise pollution, road accidents, and other associated issues [5]. According to statistics, the total number of registered automobiles in the United States reached around 290 million by the conclusion of 2022 [6]. Moreover, it is estimated that around 40% of the population dedicates at least one hour every day to commuting [7]. In recent years, there has been a significant increase in the reliance on transportation systems. As a result, it is now common for individuals in modern society to face numerous challenges related to transportation on a daily basis. These challenges include traffic congestion, limited parking spaces leading to parking problems, longer commuting times, high levels of CO2 emissions, an increased number of accidents, and various other issues. Smart transportation applications possess significant potential to tackle the challenges arising from the continuous migration of people to urban areas. They achieve this by effectively coordinating multiple traffic control systems from diverse domains, operating on a large scale, and analyzing substantial amounts of data collected from various sources. Additionally, these applications aim to enhance the safety of travel experiences. By using its expertise in computer design, data management, and sophisticated processing methods, IoT provides a viable solution to actual traffic problems. It allows for the incorporation of dispersed devices that consistently provide data to a central hub, making it easier to allocate resources and make decisions.

The use of IoT in the transportation sector may bring about a significant transformation in the data management system. This can be achieved by using AI algorithms to efficiently handle data, even in intricate scenarios involving extensive datasets associated with transportation systems. In addition, the Internet of Things (IoT) has the capability to examine traffic conditions and forecast personalized information by sorting through large amounts of data.

1.1 . Smart Transportation System

A smart transportation system (STS) integrates advanced technologies and innovative practices to enhance the efficiency, safety, and sustainability of transportation networks. Leveraging the power of the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and communication technologies, STS transforms traditional transportation into an intelligent, interconnected network. Key components include real-time traffic management, smart traffic signals, connected vehicles, and automated public transportation. Real-time data from sensors and GPS devices enables dynamic traffic flow adjustments, reducing congestion and travel times. Connected and autonomous vehicles communicate with each other and with infrastructure to enhance safety and optimize routes. Additionally, smart public transport systems use predictive analytics to improve schedules and passenger experiences.

1.1.1 Application of Smart Transportation

Within this part, we will analyze the primary existing intelligent transportation systems. The systems are categorized into seven types depending on their functionality, as shown in Figure 1.1. We categorized these systems in order to provide a systematic comprehension of the various kinds of systems and analyzed their functions in relation to smart transportation systems.

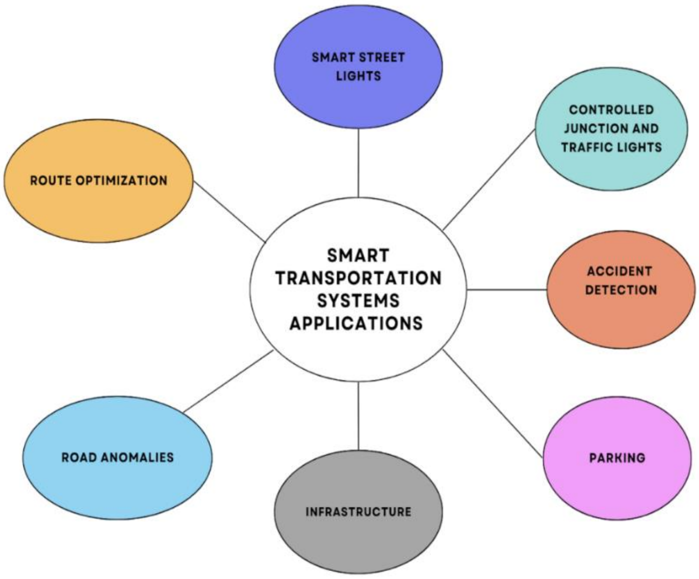

Figure. 1.1 Application of smart transportation system [8]

Route Optimization

Urban areas often experience traffic congestion, a problem that is exacerbated by the increasing number of cars on the road. To alleviate traffic congestion, route optimization suggests the most efficient route to a specified destination. Reducing traffic congestion leads to a reduction in both travel time and vehicle emissions [9]. The subject of optimizing routes has been extensively studied in the literature, with researchers using several technological techniques to the architecture of the Internet of Things (IoT).Google was an early adopter of crowdsourcing as a means of creating new services. The free Google Maps app is compatible with all contemporary mobile devices. Mobile devices often have integrated GPS, accelerometer, and gyroscope sensors. In 2009, Google introduced a new service that allows users to get traffic statistics using Google Maps [10]. The traffic data was not collected by stationary sensors or other monitoring devices. The maps application allows the user's mobile device to anonymously transmit information on their location and velocity. Google Maps now offers alternative route recommendations based on real-time traffic data to alleviate congestion.

Parking

By obviating the need of scouring parking lots for vacant spaces, facilitating the pre-emptive identification of accessible spots aids in mitigating traffic congestion and reducing pollution [11]. Several parking apps are developed to effectively monitor the availability of parking lots, provide customers reservation choices, and even integrate parking detection and alarm systems. Multiple Internet of Things (IoT) sensors have been used to detect the presence of a vehicle in a parking space and transmit this information to a centralized system. In addition, additional research use machine learning algorithms that utilize picture data to discover a large number of available parking spaces.In order to assess the availability, the authors in [12] additionally install ultrasonic sensors at each parking spot. The sensor is connected to an Arduino Uno, which utilizes an ESP8266-01 WiFi module to relay data to a cloud server. The MQTT protocol facilitates communication. The cloud server operates ThingSpeak, an Internet of Things (IoT) platform that offers users a range of administration and monitoring choices. Additionally, consumers have the option to download an Android application that allows them to conveiently book parking spots and streamline the process of making parking payments.

Road Anomalies

Road anomaly detection is crucial in smart transportation because to its direct influence on several elements of transportation. The main purpose of a road anomaly detection system is to identify and notify drivers about the presence of potholes and bumps on the road. Inadequate road conditions may lead to traffic congestion, vehicle damage, and road accidents. The author[13] suggested a CNN-based technique to detect concrete cracks in photographs captured with a hand-held camera under challenging lighting conditions. The CNN model was trained using a dataset of 40,000 pictures with a resolution of 256 × 256 pixels. The model achieved an accuracy of about 98%. According to the paper, their proposed strategy was especially efficient in detecting narrow cracks in low-light conditions, which are difficult to identify using standard methods such as Canny and Sobel edge detection.

Infrastructure

The advancement of IoT technology has greatly benefited modern transportation in several ways. It has fostered novel cognitive frameworks and innovative implementations that have enhanced transportation. Modifying the infrastructure of Intelligent Transportation Systems may greatly enhance their capabilities. The author [14] proposes a new technique of communication. The authors propose and simulate a vehicle-to-vehicle (V2V) communication architecture, based on the Internet of Things (IoT) concept of machine-to-machine (M2M) communication. The proposed architecture involves the use of GPS by cars to ascertain their position and establish communication with neighboring vehicles for the purpose of exchanging information on their speed, movements, and locations. Simultaneously, the data will be uploaded to a server. Therefore, it is possible to provide early notice to incoming traffic about abrupt changes in speed in order to avoid accidents, and to enhance guiding services by sharing information about traffic congestion with approaching cars.

1.1.2 Challenges of Smart Transportation

In this section, we address the current obstacles in smart transportation systems and explore prospective avenues for future study in this field. While smart transportation systems have been more popular owing to their capacity to provide rapid, convenient, and efficient services, they are not devoid of shortcomings.

- One of the main challenges in wireless networks is the increasing number of devices used for traffic monitoring and management, which leads to network overload. With the growing number of devices, there will be a need for an adaptive routing protocol to allocate and prioritize resources, as well as a system to store and manage massive amounts of road traffic data [15].
- Additional issues pertain to the communication between vehicles, known as vehicle-to-vehicle (V2V) communication. It is necessary to develop new certificate management systems in order to safeguard the privacy, safety, and security of infrastructure communication networks [16]. Vehicle-to-vehicle (V2V) communications may experience transmission interference or unauthorized infiltration attempts, such as taking control of the vehicle or modifying data sent to other mobile hosts, which may result in accidents.
- Another concern is to the expensive installation and intricate nature of these systems. Implementing intelligent transportation systems requires significant investments in hardware, software, and infra-

structure. Adoption of this may pose a considerable difficulty, especially in less populated urban areas and rural communities [17]. Moreover, smart transportation systems are complex and need specialized expertise in data analytics, artificial intelligence, and IoT technology. In order for intelligent transportation systems to operate properly, it is necessary for several technologies and platforms to be compatible with one other.

- Furthermore, establishing connection is of paramount significance in a smart transportation system. Efficient operation of smart transportation systems is heavily dependent on robust data and communication networks. Any interruption or failure in these networks may lead to substantial problems such as traffic congestion, delays, and safety hazards.

1.2 IoT-based Traffic Management System

The issue of traffic congestion is a significant problem in today's world, as it disrupts the daily routines of metropolitan regions and has negative impacts on the surrounding environment. The vehicle density on roadways has significantly increased due to population development and urban expansion. The issue of traffic congestion has become a prominent worry for several major cities worldwide. Traffic congestion has detrimental impacts on the fertility, competitiveness, and economics of the nation[18]. Consequently, academics have devised many strategies to address this problem. According to the report, in 2014, 54% of the global population lived in metropolitan regions. The subsequent years have also seen a surge in urban population, which has placed significant limitations on the transportation infrastructure. Due to the high cost of living in business locations, workers who reside far from their workplace are required to commute from their place of residence. While increasing the size of roadways may seem to be a reactive solution to the problem, communities should instead focus on implementing more intelligent traffic management strategies. The advancements in internet technology, particularly in terms of bandwidth and speed, have facilitated the widespread adoption of the IoT and paved the way for innumerable innovations[19]. The development of IoT is made possible by the contributions of several sectors such as embedded systems, automation, wireless sensor networks, and control systems. Effective traffic management may be achieved via the interplay of several components within the transportation system. The use of IoT is present in many aspects of transportation systems. The IoT platform enables ongoing monitoring of traffic using wireless sensors and assures timely notification of any deviations in management. Integrating traffic systems with the Internet of Things (IoT) will provide enhanced security and safety on the roads. Integrating many sensors with a dedicated website to provide real-time access to information may enhance the efficiency and safety of traffic management in embedded systems.

Figure 1.2 IoT-Based smart Traffic Management monitoring for cities [20]

Figure 1.2 depicts the installation of traffic cameras that record the vehicular density on the route. The road sensors also gather traffic data. The obtained data is sent to the server. The device used a cutting-edge spectrum sophisticated wireless gateway, enabling seamless transmission of data to a cloud service or server. The traffic signal time is allocated based on the data obtained on the density of cars on the route. Hence, the development of a traffic control system using IoT via automated vehicle counting and traffic light management is essential for the implementation of intelligent and secure road networks.

1.3 Vehicle to Infrastructure (V2I) communication

V2I communication is an essential element of intelligent transportation systems, allowing direct communication between cars and the physical components of the road, such as traffic signals, lamps, and signs. V2I systems use cutting-edge wireless communication technology to communicate up-to-the-minute information about traffic conditions, road dangers, and infrastructure status to cars, therefore improving safety and efficiency on the roads[21]. For example, Vehicle-to-Infrastructure (V2I) technology may provide drivers with information on future changes in traffic signals, enabling them to make smoother and safer adjustments to their speed. In addition, it has the capability to provide notifications of road construction, accidents, or unfavorable weather conditions ahead, allowing drivers to proactively respond. V2I communication enables the transfer of information between cars and infrastructure, leading to a reduction in traffic congestion, improved traffic flow, and a reduced risk of accidents. In addition, V2I establishes the foundation for more sophisticated applications, such as autonomous vehicle management and integration with smart cities, eventually enhancing connectivity, efficiency, and safety in the transportation ecosystem. In order to enable communication between cars and infrastructures, V2I technology deployments will need integration with intelligent system equipment as shown in Figure 1.3. The placement of devices on infrastructures is contingent upon the specific positions of the devices, the distances between them, and the overall size of the region.

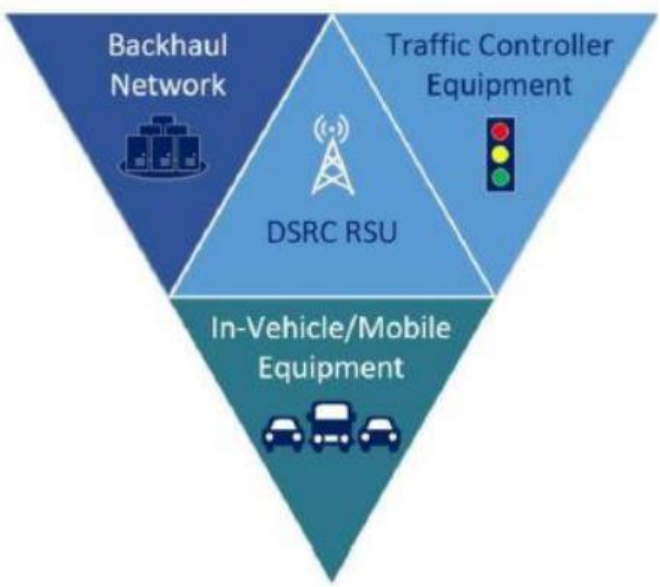

Figure 1.3 Diagram of V2I [22]

1.3.1 Significance of V2I

V2I technology primarily aims to mitigate automotive accidents, enhance overall mobility, and promote energy conservation by facilitating the exchange of information with vehicle users. Cost is another crucial feature of V2I. Regarding the safety, mobility, and environmental advantages provided by V2I, the cost is deemed to be minimal. V2I technology, with its many advantages, is seen as a crucial component of an intelligent transportation system that has the potential to revolutionize the future of transportation. This technology opens up new possibilities, including the development of autonomous cars. V2I technology, also known as Vehicle-to-Infrastructure technology, is a technological advancement that aids drivers in safely and effectively completing their journeys. Furthermore, it will aid in the design and construction of autonomous cars. Thoroughly testing all technologies and tools will aid in identifying future requirements and enhancing the autonomous car development process.

1.4 Motivation

Urban inhabitants accounted for 54% of the world population in 2014. The forecast projected an annual growth rate of around 2% until 2020, which would further strain urban transportation systems. In addition, the exorbitant cost of housing in central business districts necessitates that urban workers dwell far from their workplaces or educational institutions, resulting in the need for regular commuting between their residences and places of employment. There is a need to accommodate a greater number of automobiles on a limited number of roadways and transportation infrastructure. Frequently, when faced with a surge in traffic, the typical response is to simply expand the lanes or elevate the road surfaces. Nevertheless, communities must to prioritize the implementation of intelligent street management systems rather than only focusing on expanding their size or constructing more roadways.

1.5 Contribution of study

The integration of Internet of Things (IoT) traffic management systems with blockchain technology, notably via the Polygon approach, signifies a notable progression in intelligent transportation systems. This strategy utilizes the fast data processing and minimal delay of Polygon's Layer 2 scaling technologies to tackle the inefficiencies and security issues in conventional traffic management. The solution guarantees smooth and effective connectivity across the network by using IoT devices to gather real-time data from cars and infrastructure. The decentralized structure of the blockchain ensures the integrity and openness of data, therefore minimizing the potential for manipulation and fostering trust among parties. The Polygon method's efficient transaction processing and low costs make it well-suited for managing the substantial volume of data produced by IoT devices in urban traffic scenarios. Moreover, the scalability of Polygon enables the system to be expanded to handle the growth of metropolitan areas while maintaining optimal performance. This integration not only improves traffic flow and decreases congestion, but also facilitates the development of smart cities with improved safety and efficiency in transportation.

1.6 Problem formulation

The management of outgoing traffic is often overseen by the traffic authorities. An inherent limitation of this traffic management system overseen by the traffic police is its lack of intelligence to effectively manage traffic congestion. The traffic police official has the authority to either obstruct a road for an extended duration or allow cars on another route to proceed. The decision-making process may not always be optimal and is solely dependent on the official's judgment. Furthermore, the duration for which cars are shown a green or red signal remains constant, even when traffic lights are used. Hence, it could be incapable of resolving the issue of traffic congestion. In India, it has been observed that despite the installation of traffic lights, traffic police officers are still deployed, indicating that this system requires more human resources and is not cost-effective. To tackle these difficulties, it is necessary for government entities, technology suppliers, and urban planners to collaborate and provide a strong foundation for intelligent mobility. Through the successful resolution of these obstacles, STS has the potential to completely transform urban transportation, enhancing its efficiency, safety, and environmental sustainability.

1.7 Research objective

- To explore and enhance the capabilities of smart transportation systems (STS) through the integration of Internet of Things (IoT) technologies.
- To developed a robust algorithms and frameworks that leverage IoT data from sensors embedded in road infrastructure, vehicles, to improve decision-making processes in traffic management.
- To evaluate the impact of V2I communication on reducing accidents using novel framework.

1.8 Summary

This study investigates the creation and execution of a traffic management system that incorporates IoT technology with blockchain technology, with a distinct focus on employing the Polygon approach. The objective is to improve V2I communication, optimize the movement of traffic, and guarantee the accuracy and protection of data. In this study, python tool is used.Blockchain technology integration tackles fundamental issues in traffic management, including data manipulation, privacy anxieties, and the need for a distributed and open system. Polygon, a Layer 2 scaling solution, is selected because to its capacity to efficiently process large numbers of transactions with little delay and cheap costs, making it well-suited for the dynamic nature of urban traffic control.The Polygon algorithm is specifically intended to enhance the efficiency of Vehicle-to-Infrastructure (V2I) communication. The process involves many crucial stages: initializing the blockchain network, establishing smart contracts to govern traffic management rules, and installing validator nodes to guarantee consensus and validate data. Transactions, such as the arrival and departure of vehicles, changes in traffic signals, and reports of incidents, are documented on the blockchain to maintain an unchangeable and easily understandable record.To summarize, this study showcases the capacity of integrating Internet of Things (IoT) and blockchain technologies, specifically using the Polygon approach, to establish a resilient, secure, and effective traffic control system. Python's use in data processing and analysis significantly improves the system's capacity to manage substantial amounts of traffic data, offering immediate insights and predictive analytics to boost traffic flow and safety in metropolitan regions.

2. Review of Literature

Researchers have thoroughly investigated the use of IoT devices, including sensors, cameras, and linked cars, to establish intelligent transportation ecosystems that increase the movement of vehicles, decrease traffic congestion, and promote safety. Significant research emphasizes the use of IoT traffic management systems that utilize up-to-date information to adapt traffic signals in real-time, provide precise traffic forecasts, and enhance route optimization. These systems use sophisticated algorithms and machine learning approaches to examine traffic patterns, forecast congestion, and provide drivers with alternate routes. The literature also highlights the crucial significance of V2I communication in Smart Transportation Systems (STS). V2I technology enables seamless communication between cars and infrastructure elements such as traffic lights, road signs, and toll booths. This allows for the sharing of vital information, including traffic conditions, road dangers, and recommended speed limits. This two-way communication improves drivers' understanding of their surroundings and facilitates the advancement of self-driving and partially self-driving cars. Research has shown that Vehicle-to-Infrastructure (V2I) communication may effectively decrease traffic accidents and enhance overall road safety by delivering prompt alerts and automated reactions to possible dangers. Furthermore, the use of IoT and Vehicle-to-Infrastructure (V2I) technologies in smart transportation systems has been shown to enhance fuel economy and decrease environmental footprint. To summarize, the research suggests that the use of IoT technology in traffic management and V2I communication is crucial for the advancement of intelligent transportation systems. These technologies provide substantial advantages in terms of traffic efficiency, safety, and environmental sustainability.

2.1 IoT-based Smart Transportation system

Rashid et al., (2024)[23]Currently, intelligent transportation systems are being developed with the purpose of providing passengers with benefits. As a consequence of the introduction of cutting-edge technology such as the IoT, the transportation industry has seen significant setbacks. The most important things for different transportation networks are to protect the safety of passengers and to make the most efficient use of the time they have available. The correct design of the system is very necessary for the safety of transportation. This study use the SPIN model checker as a means of resolving the problem of ensuring correctness while maintaining compliance with system safety standards. Intelligent transportation systems that are based on the IoT have been the topic of a great deal of research; however, formal verification to ensure the correctness of these systems has gotten less attention. In order to resolve this problem, this work provides official validation of a transport system that is built on SPIN. A formal verification is carried out to ensure that the program graph is accurate. This is accomplished by supplying the program graph and LTL formulas as input to the SPIN model checker, which then assesses whether or not the properties are fulfilled using the program graph.

Prakash et al., (2024)[24]studied that the integration of communication devices facilitated by smart cities and the IoT has enhanced decision-making efficiency. Significantly, metropolitan commuters have a significant issue in the form of traffic congestion. Specialized sensors are strategically placed in industrialized nations to collect traffic data for the purpose of predicting traffic trends. Commuters are informed about traffic updates over the Internet. These techniques are not feasible when there is no physical infrastructure or insufficient Internet access. Developing nations sometimes lack roadside devices and have challenges with Internet access in distant places. Internet traffic analysis is a flourishing area of research because of the many practical applications it offers. Cutting-edge technology may be used in the intelligent IOVs to forecast and identify traffic bottlenecks. The proposed system employs ensemble learning and utilizes the averaging of important characteristics to achieve a high level of detection accuracy while minimizing computing expenses, as shown by the simulation outcomes. Comparing the lowest accuracy of 96.6% for KNN and the greatest accuracy of 98.01% for SVM, the Stacking technique outperforms both with an accuracy of 99.05%.

Dui et al., (2024)[25] stated that the use of advanced IoT technology significantly enhances the degree of intelligence in ITS and facilitates the sustainable growth of urban transportation. Nevertheless, the task of using IoT to manage traffic flow and advance Intelligent Transportation Systems (ITS) towards automation and worldwide control remains unresolved. In light of this situation, a potential traffic management model is suggested for Intelligent Transportation Systems (ITS) that utilizes the Internet of Things (IoT) to improve road awareness and transportation system response. When there are traffic congestion events, ITS may use a macro viewpoint to give the best control strategy for vehicle-to-everything supported cars (V2X-supported vehicles). This method helps regulate the traffic flow worldwide and enhances traffic efficiency. Specifically, the optimum control techniques take into account the possible crowded road segments resulting from the spread of congestion. This study examines how the decision-making behavior of V2X-supported cars in choosing their routes affects the overall functioning of the system. The simulation findings demonstrate that implementing optimum control techniques may successfully mitigate congestion and greatly enhance the performance of the transportation system by regulating the movement of cars.

Karthikeyan et al., (2023)[26] examined an Intelligent transport systems (ITS) is an upgraded version of Vehicle Ad-hoc Network (VANET) that offers enhanced assistance in various traffic control procedures. Subsequently, the prominent characteristics of the IoT are integrated with ITS. The IoT-ITS facilitates the implementation of automated mobility via connectivity and cooperation. Nevertheless, the progress of IoT-ITS is limited by the risk issues associated with data security and privacy. In order to address these challenges, a safe framework for IoT in ITS is suggested, using cognitive science. An extensive analysis is conducted to examine the hazards associated with the IoT and ITS environment. The primary goals of this security framework are to address the security requirements of the Intelligent Transport Systems and mitigate the related risk factors without making any concessions. Cognitive science is used to develop the security framework that distinguishes between authorized users of the transportation system and malevolent users. Cognitive science facilitates real-time data processing. According to the experimental findings, superior outcomes are achieved.

Chowdhury et al., (2023)[27] studied that the EMS is a vital element of ITS, with its main goal being to dispatch EVs to the site of a reported event. Nevertheless, the growing congestion in metropolitan regions, particularly during rush hours, causes EVs to arrive late in several instances, eventually resulting in elevated death rates, heightened property damage, and increased road congestion. Prior research has focused on prioritizing EVs while they are driving to a location of an incident by modifying traffic lights along their route, for as by turning the signals green. Several studies have also endeavored to determine the optimal path for an electric vehicle (EV) by considering traffic data such as vehicle count, flow rate, and clearing time at the start of the trip. Nevertheless, these efforts failed to take into account the congestion or disturbance experienced by other non-emergency vehicles located along the route of the electric car. The chosen travel routes are fixed and do not take into account dynamic traffic conditions when electric vehicles are in transit. In order to tackle these problems, this article suggests the implementation of a priority-based incident management system that utilizes Unmanned Aerial Vehicles (UAVs). The purpose of this system is to aid Electric Vehicles (EVs) in reducing their clearing time at intersections, ultimately resulting in a decrease in reaction time. The simulation results demonstrate that the suggested approach successfully reduces the reaction time for electric vehicles (EVs) by 8% and improves the clearing time around the incident location by 12%.

Sharma et al., (2023)[28]introduced an ITS method using the architecture of linked car technologies. A real-time computer vision system, based on YOLO v4, is deployed on the GPU to efficiently recognize automobiles, people, and animals. It attains a mean average accuracy of 0.9777 and a high frame rate of 74.26 fps. The locations were then sent to a cloud server, resulting in the creation of a geospatial database. The geospatial data was used to pinpoint concentrated locations on a heavily trafficked transit system. These places were then used to establish zones that serve as focal points for animal activity and areas prone to potholes. A basic warning system was triggered when the car approached areas with animals and potholes. Furthermore, a complex warning system, including of both visual and audio signals, was triggered when the vehicle neared regions with significant levels of activity. This was accomplished by using real-time IoT and cloud infrastructure applications to consistently track the whereabouts of cars and trigger certain actions depending on specific geographic areas. The proposed approach improved traffic safety and helped minimize possible collisions and accidents, which often led to traffic congestion and fatalities.

Chen et al., (2022)[29] suggested an implementing an IoT framework for an energy-efficient and intelligent street lighting system. This system would include IoT sensors integrated into smart electric poles, along with a controller to regulate LED bulbs. The sensor unit's intelligent decision-making module utilizes data on traffic flow and occupancy status to compute the intensity level. Subsequently, the intensity level is used to produce pulses of varying lengths via the utilization of a PWM dimming system. The pulses activate the LED power switch via a DALI controller, which is installed inside the LED Light Controller. To maximize the use of renewable energy sources, we utilize sustainable power systems that consist of photovoltaic solar panel units, battery storage systems, and intelligent electric power networks. Our charging battery system utilizes an MPPT-based dynamic battery charging algorithm. Through analysis of both empirical and simulated data, we have noticed that the proposed energy-efficient Smart Street lighting system effectively decreases energy use during both high-demand and low-demand periods. The energy-saving impact is not restricted just to highways, but also applies to residential and suburban pedestrian zones. Ultimately, it will decrease energy use and carbon emissions. We do a comparative analysis of the suggested technologies and existing lighting systems, with a specific emphasis on energy consumption. The experiment findings also confirm the effectiveness of the proposed dynamic battery charging method, which depends on the performance of the battery storage PV solar panel system.

Mahmood et al., (2022)[30] studied the advent of modern technologies such as cloud computing and the IoT has drastically transformed the patterns in the digital realm to benefit mankind. These applications are often used, especially in the context of smart cities and their many components. An example of such an application is the MTS. The IoT-enabled MTS has the capability to effectively handle the growing intricacies of modern ship transportation. The most crucial and necessary duty in getting Big Data in IoT-enabled MTS is to guarantee safe and rapid access to data from several smart IoT devices. Therefore, we have developed an authenticated key agreement method using a Physically Unclonable Function (PUF) to overcome this challenge. This technology enables the mobile user and IoT node to authenticate each other over the Cloud-Gateway. The authentication procedure takes place before to the real-time interchange and transmission of data in an IoT-enabled MTS. By integrating Physical Unclonable Function (PUF) technology into our system, we provide unmatched defense against physical security risks. We conduct a comprehensive security study, assuming the defined threat model, to demonstrate the robustness of our approach. The performance of our solution is achieved by the implementation of security measures, effective communication, and efficient computing. It has been noticed that our approach demonstrates a 37.3% improvement in communication efficiency and a 9.7%

reduction in calculation overhead. Furthermore, the efficacy of our solution's network performance is proved by its deployment in NS3.

Prasetyawan et al., (2021)[31]presented a prototype of a smart system designed to enhance safety while riding, using IoTtechnology. This system comprises connection devices such as helmets, motorbikes, and individuals (via smartphones). The system is well integrated into helmets and bikes, including many essential electrical components, including the NodeMCU microcontroller, accelerometer-gyroscope sensor, GPS module, flex sensor, buzzer, and relay. The helmet, motorcycles, and riders are interconnected across the internet using the android application interface. The application is able to monitor the current status and location of riders in real-time by using Firebase's real-time database. This system has four independent components: helmet identification, tiredness detection, accident detection, and notification with the specific location of the accident, which may be observed by others. These traits represent the culmination of previous comparable investigations. The results of this testing of the system prototype showed that all system features were operating well. The precision of helmet recognition is 100%, the precision of sleepiness detection is 87%, and the precision of accident detection is 90%. Others may monitor and follow the status and position of the rider with the android application.

Al-Ali et al., (2021)[32] studied that smart Cities include a multitude of intelligent applications, including smart transportation. Presently, multiple transportation models are shifting from individual ownership to collective and decentralized ownership. Examples of these models include Uber, uDrive, and Lyft, which use the notion of scattered automobiles that has been implemented worldwide. These variants are used for transporting individuals for both intercity and intracity journeys. However, the use of short-range urban transportation services such as bicycles inside enclosed areas, campuses, residential complexes, and public parks is not being completely optimized when compared to the widespread usage of cars. This paper proposes the development of a Smart Mobility Shared Transportation System specifically designed for short-distance travel. The system consists of an edge computing device affixed to an electric bike (e-bike), a charging station, a web application, a mobile application, and a server. Every bicycle is considered an individual entity that is connected to the Internet, hence categorizing it as an IoT device. The bike's geographical coordinates, state of maintenance, and relevant environmental variables are sent to a remote server for the purpose of data analysis and visualization, facilitated by a tailored web application designed for administrators. A smartphone application is created to facilitate consumers in initiating their use of the bicycle sharing system. The suggested system has the capability to be expanded in order to create a distributed shared mobility system that can accommodate a large number of bicycles.

Ayoub et al., (2020)[33]examined the process of choosing the most suitable technology for IoT contexts. IoT applications, such as advanced tracking solutions in automotive or transportation systems, need the ability of the IoT device to move between several IoT technologies. In this context, it is crucial to choose the most suitable technology for connection by considering many aspects. We examine four LPWAN technologies and analyze two well recognized multi-attribute decision-making algorithms, TOPSIS and SAW, to determine the most suitable IoT technology based on characteristics such as bit rate, coverage, power consumption, and more. These two algorithms were used to determine the optimal technology based on the specific needs of the application. The data collected indicate that the TOPSIS technique outperforms the SAW method in both technology selection and sorting. Nevertheless, the computational time required for SAW is shorter.

Dass et al., (2020)[34]presented a reliable service provisioning method for the architecture of Safety-as-a-Service (Safe-aaS) in intelligent transport systems based on the IoT. A Safe-aaS architecture often utilizes decision virtualization to dynamically provide tailored safety-related choices to different end-users. Road transportation is the specific context in which we use Safe-aaS to provide reliable judgments. However, the effectiveness and precision of the judgments made rely on the security, privacy, and reliability of the sensor nodes involved and the path over which data is sent. We provide a trust assessment model that calculates the reliability of the data produced by these nodes. In addition, we examine both direct and indirect trust mechanisms for each sensor node and regularly update their trust metrics. Using these metrics, we assess the reliability of each data item obtained from the network. We develop an integer linear programming (ILP) model to choose the most suitable data for decision-making, while mitigating the impact of unauthorized sensor nodes. In addition, we demonstrate that the ILP issue we have defined is NP-hard. To address this problem, we use a dynamic programming technique. The experimental findings demonstrate that our trust assessment model achieves an attack detection rate of over 8% and reduces the false attack detection rate by 13% in a network including 50% hostile nodes, when compared to the benchmark systems. The suggested method for selecting trustworthy data surpasses many current greedy algorithms.

Sodhro et al., (2019)[35] analyzed that the high mobility in ITS, especially in Vehicle-to-Vehicle (V2V) communication networks, allows for broader coverage and quick assistance to users and surrounding networks. Nevertheless, this increased mobility also results in a decrease in the overall system performance due to variations in the wireless channel. Ensuring enhanced QoS for transmitting multimedia in V2V communication across next generation networks, namely edge computing platforms, is a very challenging endeavor. The main reason for this is the extensive mobility of automobiles and the heterogeneous characteristics of upcoming IoT-based edge computing networks. This research provides three distinct contributions within this particular situation. The technique proposed is a QoS-aware, green, sustainable, reliable, and available (QGSRA) approach to facilitate multimedia transmission in V2V across future IoT-driven edge computing networks. Furthermore, it incorporates an innovative QoS optimization method in V2V communication while transmitting multimedia content across edge computing systems based on the IoT. Finally, it suggests QoS measurements like as energy efficiency (greenness), battery charge usage (sustainability), packet loss ratio (reliability), and coverage (availability) to evaluate the performance of V2V networks. The efficacy of the QGSRA approach has been validated by the successful testing of real-time automobile datasets. The findings demonstrate that it surpasses current methods, establishing itself as a formidable candidate for multimedia transmission in V2V using self-adaptive edge computing systems. There is a wide range of authors who studied on the IoT-based smart transportation system and give their findings as shown in Table 2.1.

Table 2.1: Comparison of reviewed literature

Authors [Ref.]	Year	Technique	Outcome
Rashid et al., [23]	2024	SPIN	According to the findings, the SPIN model has verification to ensure the correctness of these systems has gotten less attention.
Prakash et al., [24]	2024	Ensemble learning	The Stacking approach surpasses both KNN, which has the lowest accuracy of 96.6%, and SVM, which has the highest

			accuracy of 98.01%, with an accuracy of 99.05%.
Dui et al., [25]	2024	IoT	The simulation findings demonstrate that implementing optimum control techniques may successfully mitigate congestion and greatly enhance the performance of the transportation system by regulating the movement of cars.
Karthikeyan et al., [26]	2023	IoT	According to the experimental findings, superior outcomes are achieved.
Chowdhury et al., [27]	2023	Dynamic UAV	The simulation results demonstrate that the suggested approach successfully reduces the reaction time for electric vehicles (EVs) by 8% and improves the clearing time around the incident location by 12%.
Sharma et al., [28]	2023	YOLOv4	The proposed approach improved traffic safety and helped minimize possible collisions and accidents, which often led to traffic congestion and fatalities.
Chen et al., [29]	2022	MPPT-based dynamic	The findings of the experiment also verify the effectiveness of the dynamic battery charging strategy that was recommended. This technique is dependent on the efficiency of the PV solar panel system that stores renewable energy in batteries.
Mahmood et al., [30]	2022	PUF	Our approach demonstrates a 37.3% improvement in communication efficiency and a 9.7% reduction in calculation overhead.
Prasetyawan et al., [31]	2021	IoT	The precision of helmet recognition is 100%, the precision of sleepiness detection is 87%, and the precision of accident detection is 90%.
Al-Ali et al., [32]	2021	IoT	The suggested system has the capability to be expanded in order to create a distributed shared mobility system that can accommodate a large number of bicycles.
Ayoub et al., [33]	2020	TOPSIS	The TOPSIS technique outperforms the SAW method in both technology selection and sorting.
Dass et al., [34]	2020	ILP	The experimental findings demonstrate that our trust assessment model achieves

			an attack detection rate of over 8% and reduces the false attack detection rate by 13% in a network including 50% hostile nodes, when compared to the benchmark systems.
Sodhro et al., [35]	2019	QGSRA	Using self-adaptive edge computing systems, the results reveal that it is superior to the approaches that are already in use, establishing itself as a serious contender for the transmission of multimedia in vehicle-to-vehicle (V2V) environments.

2.2 Traffic Management and Vehicle to Infrastructure communication using IoT

Kumar et al., (2024)[36]examined the use of IoT technology and sensor fusion methods into contemporary transportation systems to improve efficiency, safety, and road condition evaluation. The study highlights the significance of V2V communication through DSRC Dedicated Short Range Communication, Threshold Based Algorithms (TBA), and Dynamic Time Warping (DTW). Additionally, it introduces a new approach to IoT multi-sensor fusion hardware model, specifically designed to detect different road conditions, including clean and rough surfaces. The suggested model incorporates a multi-sensor module to gather and analyze real-time data on the condition of the road surface. This data is then classified into two categories: flat and clean, or bumpy and rough, depending on their smoothness index. This not only alleviates the expense of constructing road infrastructure, but also minimizes the damage caused to vehicles as a result of bad road conditions. The proposed project aims to identify road abnormalities via road surface monitoring and enhance the future navigation systems for cars, including autonomous and low ground clearance luxury automobiles. The described IoT multi-sensor fusion hardware architecture utilizes pitch orientation and category data from its sensors to identify road smoothness and road driving terrain. The development and implementation of an IoT road health monitoring system provide opportunities for further investigation into improved and advanced route guiding systems that prioritize road health.

Naeem et al., (2024)[37]focused on developing a smart transportation plan for both emergency autonomous cars and routine autonomous vehicles in a vehicle-to-everything (V2X) environment. All cars are completely self-driving, and all EAVs communicate via autonomous junction management to handle traffic conditions. When an autonomous emergency vehicle joins the road, an autonomous intersection management system designates this vehicle with a high priority, while assigning all other autonomous cars with a low priority. By adhering to the priority queue concept and the FIFO (First-In-First-Out) rule, cars are able to operate smoothly, hence minimizing the occurrence of crashes on the road. The simulation work is carried out using Simulation of Urban Mobility (SUMO), where all recommended techniques are implemented on various routes in Pakistan. Avoid Multan by using other routes such as the M2 highway and Nishtar roads. Based on the results of our strategy simulation, the M2-motorway route has a completion time of 8.50 seconds for autonomous emergency cars, while standard autonomous vehicles require 10.55 seconds to complete the route. The findings indicate that the suggested algorithm is effective in decreasing the average time delay caused by the algorithms and the associated variation for various autonomous cars. This demonstrates the efficiency and fairness of the proposed approach in managing autonomous intersections.

Hazarika et al., (2024)[38] examined a Dynamic Traffic Light System (DTLS) plays a crucial role in autonomous driving inside urban traffic. DTLS utilizes image analysis to calculate the precise timing of light signals based on the dynamic changes in road traffic. In traditional traffic light systems, light signals are activated at predetermined or regular time intervals, regardless of the present traffic volume on the route. The static nature of the traffic signal system leads to excessive waiting time on the road, ultimately resulting in traffic congestion, environmental pollution, and potential health issues. The intelligent traffic signal system tackles these problems by using self-learning algorithms and dynamically permitting traffic flow based on real-time traffic density. This study presents a vision-based DTLS (Dynamic Traffic Light System) that utilizes the YOLO object identification method to accurately identify and count the total number of cars at a traffic light junction. The traffic lights are calibrated according to the calculated traffic flow in order to minimize the total delay at that intersection. Furthermore, the traffic intersections are equipped to connect with the other intersections in order to convey the total traffic delay detected. The purpose of this delay is to provide priority to traffic that is traveling through important areas such as schools, workplaces, hospitals, and so on. The objective of the study is to reduce the additional costs involved in both traffic calculations (by using approximation computing) and communication networks (by employing low-power technologies of IEEE 802.15.4 standard, such as DSME MAC and/or LoRaWAN). The suggested solution effectively achieves its goal of enhancing smart city infrastructure by optimizing the flow of traffic. In addition, the study presents a technique for establishing green traffic channels specifically designed for emergency vehicles.

Alhaj et al., (2023)[39]explored the development of a global system that integrates and connects vehicles with VANET, IoT, and AI technologies. The objective of this paper is to assess the feasibility and effectiveness of a proposed project in a specific region of Jordan. The project aims to decrease the occurrence of accidents by implementing specialized traffic regulations in the study area. This will be achieved by utilizing a cloud database that stores private information for each vehicle and collects real-time speed data as the vehicles travel. When a motorist surpasses the speed limit set by the Traffic Department, they are notified by warning messages indicating their violation. If the driver fails to acknowledge these warnings, they would be subject to a monetary penalty. The project aims to optimize the usage of VANET network services, with a particular emphasis on increasing public safety applications that include the interchange of data between autos and RSUs.

Liu et al., (2023)[40] examined that the majority of smart cities have significant traffic problems on a daily basis. The primary obstacle faced by smart cities is the implementation of an efficient and economical traffic management system, with some areas being automated. This book proposes the use of a cloud-assisted IoT-ITS to address the difficulties faced in traffic management. The IoT sensor integrated camera is strategically placed at each corner of the traffic signal to monitor the movement of vehicles. In addition, the refined vehicle flow data is sent to the cloud processes. An algorithm is used to analyze the data collected from different signal corners in order to recognize the direction of traffic and regulate the operation of signal lights. An alarm notice is sent to the closest traffic control center via IoT sensors when there is traffic congestion. The simulation study demonstrated that the proposed CIoT-ITS system was capable of effectively and automatically monitoring and managing the flow of vehicles. The suggested system has undergone validation using the optimization parameter, demonstrating superior performance compared to traditional approaches.

Lihore et al., (2022)[41] described the development and execution of an ATM using ML and IoT technologies. The proposed ATM system utilizes the DBSCAN clustering method, which is rooted in machine learning, to detect any unwanted anomalies. The proposed ATM model dynamically adapts traffic signal schedules in response to real-time traffic conditions and predicted movements from nearby crossings. By implementing a progressive system that drives vehicles through green lights, it efficiently decreases travel time and mitigates traffic congestion by enabling seamless transitions. The results of the experiments reveal that the proposed ATM system performed better than the traditional method of traffic management. Furthermore, it is positioned to be a leading alternative for transportation planning in smart-city-based transportation systems by virtue of its superior performance.

Mohapatra et al., (2022)[42] stated that the rapid increase in population has a direct impact on road vehicles. The exponential increase in the number of automobiles is the main factor contributing to traffic congestion, pollution, and loss of life due to accidents. This research presents a cross-point collision avoidance (CCA) model that enhances the capacity to forecast the behavior of nearby cars and road-crossing locations. The system utilizes a two-phase strategy, including vehicle-to-infrastructure and V2V communication models. This is done to prevent accidents or collisions when vehicles cross paths at turning points on urban roads. In order to carry out this task, we used sensors and beacons that are both static and dynamic in nature. We used the RMATLAB17 simulators to assess the practicality and viability of the suggested methods. The simulation findings have been verified in accordance with the safety requirements set by the government. The CCA model has a safety accuracy of 94.31% on average across various road shapes.

Kanthavel et al., (2021)[43] studied that V2I communication is a wireless communication framework that enables automobiles to share data with infrastructure. V2I connection, often used in wireless technology, facilitates bidirectional communication using a combination of hardware, software, and firmware. This connectivity is utilized to support various systems such as lane signs, road signs, and lighting systems. V2I offers extensive security, mobility, and environmental advantages via the collection and exchange of a large amount of data. Automobiles, which have long been a cherished aspiration. Now is the moment to develop a proficient and secure self-driving car that enables universal participation in this industry. To facilitate this transition, the automotive ecosystem must also undergo transformation. This initiative aims to enhance transportation safety and increase the quality of transportation services. Additionally, it will provide entertainment via innovative and adaptable solutions. This study focused on thoroughly examining the extensive knowledge and understanding of V2I, namely its role in communication. Ultimately, this study also emphasizes the practical uses of V2I-driven wireless technology. The research examined the performance of the V2I by using several metrics pertaining to execution time, data transmission speed, and resource allocation.

Elsagheer et al., (2021)[44]presented a novel traffic management system that utilizes the current VANET and IoV technologies. In order to ensure compatibility with future traffic systems and Smart Cities, the system that has been suggested has been created. Within the scope of this research, the framework of our suggested ITMS and STS controller was given. They demonstrated a method that takes into account the needs of upcoming smart cities in order to monitor the flow of local traffic at a junction. Achieving fairness, reducing travel time, promoting efficient traffic flow, reducing congestion, and giving precedence to emergency vehicles are the goals of this strategy. It is clear from the results of the simulation that the suggested system is superior to the conventional management method. Furthermore, it has the potential to be considered a viable option for the traffic management system in the Smart Cities of the future. Both the average waiting time and the number of autos that are serviced are optimized via the use of the adaptive methodology, which is an efficient method. In addition, we provide the prototype of the working hardware implementation for STS.

Sheikh et al., (2020)[45]examined the estimate of traffic incidents using a hybrid observer (HO) approach and identifies traffic incidents with an enhanced automated incident detection (AID) technology that relies on the lane-changing speed mechanism in highway traffic. Furthermore, we used a probabilistic approach to collect data on traffic information via the utilization of V2I communication. In addition, we used a HO technique to precisely forecast the likelihood of a traffic incident. It has been shown via the practical results and analysis derived from simulations that the suggested approach is superior to the techniques that are currently in use in terms of accurately anticipating traffic incidents, and it is also quite similar to the theoretical occurrence.

Sherazi et al., (2019)[46] suggested a network architecture that combines different wireless interfaces (such as WAVE, WiFi, and 4G/LTE) installed on on-board units. It uses the radio over fiber approach to create a network connection that is aware of the context. This network architecture, including many components, is designed to meet the need for extensive connectivity in VANETs. The objective is to enhance the scalability and flexibility of VANETs for the IoV, hence facilitating the provision of diverse emergency services. The design employs the Best Interface Selection (BIS) algorithm to continually provide reliable connection over the most optimum wireless interface. Uninterrupted connection is crucial for effective data forwarding in V2I communication, making it important to enable. By doing this, it successfully circumvents any possible vulnerability that may lead to a system failure. Moreover, the simulation findings provide strong evidence for the suitability of the proposed architecture in the context of the IoV, since it is capable of efficiently managing diverse applications across many wireless technologies. There is a wide range of authors who studied on the traffic management and vehicle to infrastructure communication using IoT and give their findings as shown below.

Table 2.1: Comparison of reviewed literature

Authors [Ref.]	Year	Technique	Outcome
Kumar et al., [36]	2024	TBA	IoT multi-sensor fusion hardware architecture utilizes pitch orientation and category data from its sensors to identify road smoothness and road driving terrain.
Naeem et al., [37]	2024	FIFO	The findings indicate that the suggested algorithm is effective in decreasing the average time delay caused by the algorithms and the associated variation for various autonomous cars.
Hazarika et al., [38]	2024	YOLO	The suggested solution effectively achieves its goal of enhancing smart city infrastructure by optimizing the flow of traffic.
Alhaj et al., [39]	2023	IoT	The simulation was conducted with OMNeT++ version 5.7 on Debian 11, Linux 5, and GNOME 3 operating sys-

			tems. Being a network simulator, this application is a validated open-source software that has obtained scientific validation.
Liu et al., [40]	2023	CIoT-ITS	The simulation study demonstrated that the proposed CIoT-ITS system was capable of effectively and automatically monitoring and managing the flow of vehicles.
Lihore et al., [41]	2022	ATM	According to the findings of the experiments, the proposed automated teller machine system outperformed the conventional method of traffic management and is well positioned to become the most popular option for transportation planning in relation to smart-city-based transportation systems.
Mohapatra et al., [42]	2022	CCA	The simulation findings have been verified in accordance with the safety requirements set by the government. The CCA model has a safety accuracy of 94.31% on average across various road shapes.
Kanthavel et al., [43]	2021	IoT	The research examined the performance of the V2I by using several metrics pertaining to execution time, data transmission speed, and resource allocation.
Elsagheer et al., [44]	2021	Adaptive method	The adaptive technique efficiently reduces the average waiting time and optimizes the number of automobiles that are serviced.
Sheikh et al., [45]	2020	HO	The empirical results and analysis derived from simulations demonstrate that the suggested approach surpasses current methodologies in accurately forecasting traffic incidents, closely aligning with the theoretical expectations.
Sherazi et al., [46]	2019	BIS	The simulation findings provide strong evidence for the suitability of the proposed architecture in the context of the IoV, since it is capable of efficiently managing diverse applications across many wireless technologies.

3. Research Methodology

This chapter outlines the research techniques used to examine the effectiveness of IoT-enabled traffic management and V2I communication in STS. For the purpose of providing a thorough knowledge of the technical and practical implications of these breakthroughs, the research adopted a mixed-methods approach, which included both quantitative data analysis and qualitative case studies. Firstly, a thorough examination of existing literature is carried out to determine the fundamental elements and most effective methods in Internet of Things (IoT) and Vehicle-to-Infrastructure (V2I) technologies[1]. Subsequently, a sequence of simulations and real-world tests are devised to evaluate the efficiency and dependability of these systems under different traffic scenarios. Information is gathered from many sources such as traffic sensors, linked cars, and infrastructure nodes. This data is then examined using sophisticated machine learning algorithms to identify trends, forecast traffic movement, and enhance signal timings. In addition, qualitative interviews are undertaken with industry experts and stakeholders to get insights into the actual difficulties and advantages of deploying these technologies. The technique moreover incorporates a comparative examination of conventional traffic management systems in contrast to IoT-enabled systems to emphasize enhancements in efficiency, safety, and sustainability.

3.1 Research methodology

The concept of V2B communication, also known as vehicle-to-blockchain communication, will be investigated in this section with regard to the Internet of Things (IoT) and vehicle communication in the context of intelligent transportation systems. The transfer of data between automobiles and the blockchain technology that drives the transportation system is referred to as vehicle-to-blockchain communication, or V2B communication for short. To ensure that communication between automobiles and the blockchain network is both safe and transparent, we suggest a solution that makes use of blockchain technology.

3.1.1 Blockchain-based vehicle ownership

The blockchain technology offers a viable alternative for revolutionizing automobile ownership because to its transparent, secure, and unchangeable characteristics. This section explores the fundamental elements of blockchain-based car ownership, which include the conversion of vehicle markings into digital form, the establishment of a novel procedure for creating vehicle marks, the representation of vehicle ownership using ERC1155 NFTs, and the implementation of a scoring system to monitor driver traffic infractions.

Digitizing and verifying vehicle marks

Within the realm of blockchain-based car ownership, the conventional process of documenting vehicle identification undergoes a groundbreaking shift as it is converted into a digital format. Through the use of the decentralized and unchangeable characteristics of blockchain technology, car markings, including manufacturer marks and production years, are safely converted into digital format and saved. This procedure guarantees the authenticity and accuracy of these marks, offering stakeholders a dependable and unalterable source of information. The process of converting vehicle markings into digital format promotes openness within the ownership ecosystem. It allows stakeholders to easily authenticate the validity of individual marks, hence minimizing the risks linked to counterfeit or illegal markings. Through the use of the blockchain, those with a vested interest may verify the source and chronological record of a vehicle's identification, therefore building a sense of trust and assurance in its genuineness.

International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

In addition, the blockchain provides a distinct digital identity to every car, therefore increasing the security and transparency of ownership data. The blockchain records this digital identity, enabling safe and transparent monitoring of ownership transactions and modifications. The decentralized structure of the blockchain guarantees that the ownership history of a vehicle is resistant to tampering, offering a dependable and verifiable record.

Vehicle Ownership Representation

Vehicle ownership on blockchain is implemented using ERC1155 tokens to symbolize ownership. Every ERC1155 non-fungible token (NFT) is associated with a certain vehicle and includes essential details about ownership. The NFTs function as digital ownership certificates, assigning a unique identification to each vehicle and maintaining a traceable record of ownership history. Utilizing blockchain technology guarantees that the transfer of car ownership is both safe and transparent, while also being very resistant to manipulation. The ERC1155 standard provides a structure for including comprehensive vehicle details as characteristics inside the NFTs. Every ERC1155 NFT that represents a vehicle has the capability to hold important information, including the vehicle identification number (VIN), make, model, manufacturing specifications, maintenance records, and other vital facts. These characteristics provide a thorough and unchangeable account of the vehicle's past and specs. Through the implementation of the ERC1155 standard, transparency is heightened, fostering the establishment of confidence among all parties concerned.

Vehicle scoring system

The incorporation of a score system into the V2B (Vehicle-to-Blockchain) technologies augments road safety and accountability. By using the blockchain's capacity to document and authenticate data, the scoring system monitors and logs traffic infractions linked to individual vehicles and their drivers. This approach assigns a score or rating to individual automobiles depending on how well their drivers follow traffic laws and regulations. The scoring method functions as a motivator for safe driving conduct, while also allowing stakeholders, such as insurance companies or authorities, to evaluate the level of risk connected with certain cars or drivers.

Technical Implementation

Ensuring transparent and secure vehicle ownership, uniform tokenization, safe driving habits, and efficient insurance-related activities are crucial aspects of the technological execution of contracts in the blockchain-based car ownership architecture. Figure 3.1 provides a succinct summary of the architecture. It allows for the use of digital vehicle identification, simplified proof of ownership, and more features. The diagram highlights the connections between important agreements, showcasing their significance in creating a strong and dependable system for owning vehicles.

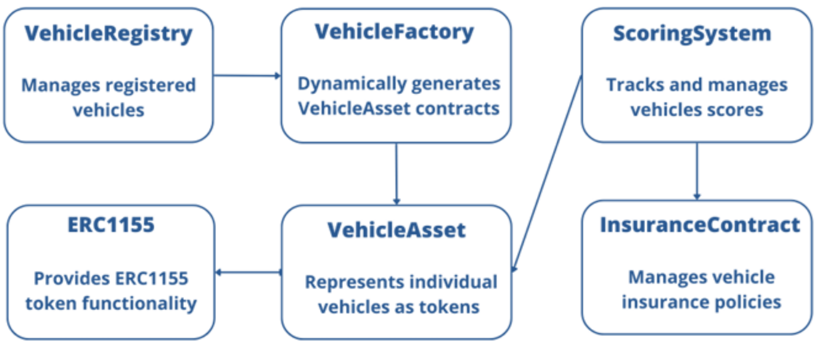

Figure 3.1 Blockchain-based vehicle ownership contracts

3.1.2 Blockchain-based ticket management for V2X

This section presents a ticket management system that use blockchain technology to enhance transparency and reliability in the travel industry. The system includes functionalities such as ticket booking and checking for availability, with explicit illustrations for taxi services and bus journeys. The decentralized nature of the system ensures integrity and prevents unauthorized adjustments or errors in reservations.

Ticket Reservation and Availability Checking

Within the ticket management system that operates on blockchain technology, customers have the ability to get tickets for their preferred travel dates and locations. The reservation procedure is characterized by transparency and efficiency, enabling users to effortlessly obtain their tickets. In addition, the system offers a function that allows users to check the availability of tickets in real-time. Users may easily confirm the ticket's availability by specifying factors such as date, destination, and ticket type. This guarantees that consumers receive the most current information about ticket availability, allowing them to make well-informed choices when booking.

3.1.3 Data Integration and Validity

Every block inside a blockchain has specific information, such as transactions, and is given a distinct hash, serving as a digital identifier. A cryptographic algorithm is used to construct the hash, which serves as a unique identification for the block. Data integrity is maintained by including the hash of the preceding block in the chain, thereby establishing a continuous and uninterrupted sequence. Any endeavor to modify data inside a block would need the recalculation of the hash for that block and all following blocks, leading to hash inconsistencies and indicating tampering. In addition, the blockchain utilizes a Merkle tree structure to ensure the integrity of transactions inside each block. The hierarchical structure involves the combination of transactions, their hashing together, and the repetition of this process until a single hash, referred to as the Merkle root, is achieved. The Merkle root ensures the integrity of all transactions in the block, enabling participants to easily verify individual transactions by utilizing their associated data and location in the tree. This eliminates the need to analyze the whole contents of the block.

Data integration and data veracity are crucial in the context of V2X communication. Blockchain technology offers effective answers for these difficulties by facilitating worldwide data integration, guaranteeing the authenticity of shared data, preserving the unchangeability of recorded transactions, and providing precise timestamps for operations. These characteristics enhance the dependability and clarity of the V2X ecosystem, enabling efficient communication and cooperation among cars, infrastructure, and other organizations.

GlobalDataIntegration: Blockchain technology facilitates the incorporation of V2X data on a worldwide level. The decentralized structure of blockchain enables safe sharing and access of data from many sources and governments. The worldwide integration guarantees a cohesive and dependable origin of V2X data, enabling efficient communication and cooperation among vehicles, infrastructure, and other organizations across international boundaries.

Validityof Shared Data: The data sent inside the V2X ecosystem undergoes verification and validation processes using blockchain technology. The blockchain's immutability guarantees that once data is recorded, it cannot be modified or tampered with. This feature ensures the accuracy and legitimacy of the data that is provided, hence increasing the level of confidence among the users in the V2X network.

Figure 3.2 depicts the incorporation of the blockchain layer and the application layer for V2X communication. The blockchain layer is shown as a sequence of linked blocks, guaranteeing the immutability and integrity of data. The application layer encompasses a range of components, including automobiles, traffic lights, radars, IoT devices, Wi-Fi, and EV charging stations. These components reflect the numerous entities inside the network. This integration provides the real-time monitoring and coordination of multiple organizations, allowing for accurate decision making. It fosters confidence and ensures the integrity of the transferred data inside the network.

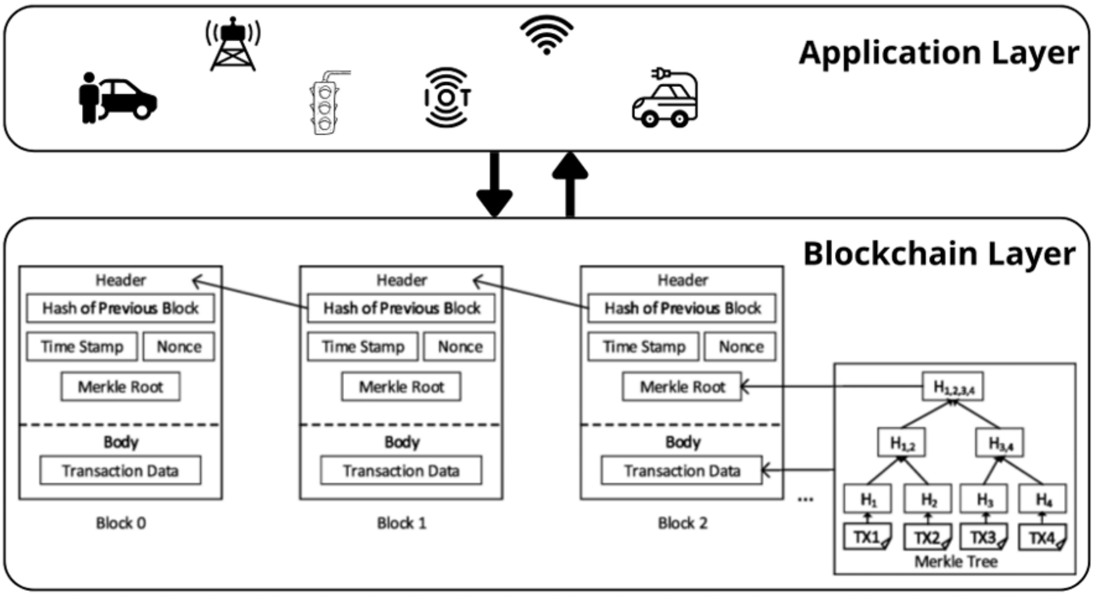

Figure 3.2 Blockchain-based application layers integration for vehicle to Infrastructure communication

3.1.4 Blockchain–IoT Integration

The integration of blockchain technology with IoT devices offers many benefits to the V2X communication system. This section examines the incorporation of blockchain technology with the Internet of Things (IoT), with a specific emphasis on enforcing penalties, validating information, monitoring in real-time, and ensuring secure messaging and connection between IoT sensors and cars.

Penalty Enforcement

The integration of blockchain and IoT may improve the enforcement of penalties for rule infractions in the V2X system. IoT sensors identify and record infractions, such as excessive speed or unlawful movements, while blockchain technology guarantees the permanence of documented transgressions. Smart contracts may automate the execution of penalties by initiating activities like imposing fines or subtracting penalty points from drivers' records. The blockchain's openness and integrity guarantee the precise enforcement and recording of fines.

Validation of Information

Integrating blockchain provides a dependable method for verifying information in the V2X ecosystem. Internet of Things (IoT) devices, such as sensors in vehicles or infrastructure, have the capability to gather and send data to the blockchain. The data undergo verified using consensus procedures to ensure their correctness and validity. By using the decentralized nature and consensus protocols of blockchain, the V2X system may have confidence in the verified information, hence enhancing data integrity and dependability.

Real-Time Monitoring

The combination of blockchain with IoT allows for the real-time monitoring of several parameters inside the V2X system. Internet of Things (IoT) sensors embedded in cars and infrastructure constantly gather and send data, including information on traffic conditions, road dangers, and weather updates, to the blockchain. The real-time data may be accessed by all users in the network, enabling prompt decision-making, effective traffic management, and improved situational awareness for drivers.

Secure Messaging and Communication

Furthermore, alongside conventional secure messaging and communication techniques, a hidden channel based on blockchain technology may be used to augment the security and confidentiality of communications sent between IoT sensors and cars. This clandestine channel enables inconspicuous communication by using the underlying blockchain technology for ensuring integrity and authentication. The construction of a blockchain hidden channel requires many technological procedures. The messages from IoT sensors are encoded using steganography methods to insert them into blockchain transactions. The hidden messages are then altered and inserted into the payload of these transactions, giving the appearance of normalcy to external observers. An encrypted key exchange protocol is used to create mutually agreed secret keys between the IoT sensors and cars, guaranteeing allowed access to the hidden communications. At the receiving end, cars use decoding techniques to extract and decrypt the hidden messages from the blockchain transactions. Confidentiality and integrity are ensured via the use of symmetric or asymmetric encryption techniques and digital signatures for authentication. Methods to thwart steganalysis are used by carefully choosing encoding techniques, payload location, and transaction characteristics to preserve the hidden nature of the communication. The IoT sensors have the capability to establish communication with the blockchain in order to access the vehicle's information and the owner's wallet address. This allows for the implementation of a grading system and the imposition of fines for any infractions. The blockchain facilitates smooth communication across various transportation modes and adds an additional layer of value to smart city transportation systems

4. Results and Discussion

Overview

This chapter presents and analyzes the outcomes of our inquiry into STS, specifically focusing on IoT-enabled traffic management and V2I communication. The findings illustrate the significant impact that the integration of IoT technology may have on urban transportation networks. We developed a preliminary version of a traffic management system that utilizes the IoT technology. This system involves gathering real-time information from a range of sensors, traffic cameras, and linked automobiles. The technology effectively demonstrated enhanced traffic flow and decreased congestion by implementing dynamic traffic signal modifications and optimizing route planning. Our analysis revealed a significant reduction in average travel times and vehicle idle times at intersections, highlighting the efficiency of the proposed system.

The V2I communication aspect of the study also yielded promising results. By enabling direct communication between vehicles and infrastructure components, such as traffic lights and road signs, we observed enhanced situational awareness for drivers and timely responses to traffic conditions. For instance, vehicles received real-time updates on traffic light status, leading to smoother transitions and re-

International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

duced instances of abrupt stopping. Additionally, V2I communication facilitated better handling of emergency situations, with priority signals for emergency vehicles ensuring quicker response times and enhanced safety.

The data from our implementation indicated notable environmental benefits as well. The optimized traffic flow and reduced idle times led to a decrease in fuel consumption and emissions, contributing to a more sustainable urban environment. However, our study also identified several challenges, including the need for robust data security measures to protect against potential breaches and ensuring interoperability among diverse IoT devices and systems.

4.1 Result and discussion

Finally, the obtained results are compared with the existing approaches. The results are discussed in the below.

Blockchain Throughput Comparison

In order to assess the transaction-handling capabilities of several blockchains, we performed stress testing simulations on Ethereum, Binance Smart Chain (BSC), Avalanche, and Polygon. To effectively implement our strategy, it is crucial to evaluate different blockchains due to the significant amount of interaction involved. Figure 4.1 demonstrates notable variations in transaction throughput across the various blockchains. These findings indicate that Polygon is the most scalable blockchain for our strategy. The system's ability to handle significant interactions necessary for our Vehicle-to-Blockchain (V2B) communication system is well-suited due to its high throughput capacity.

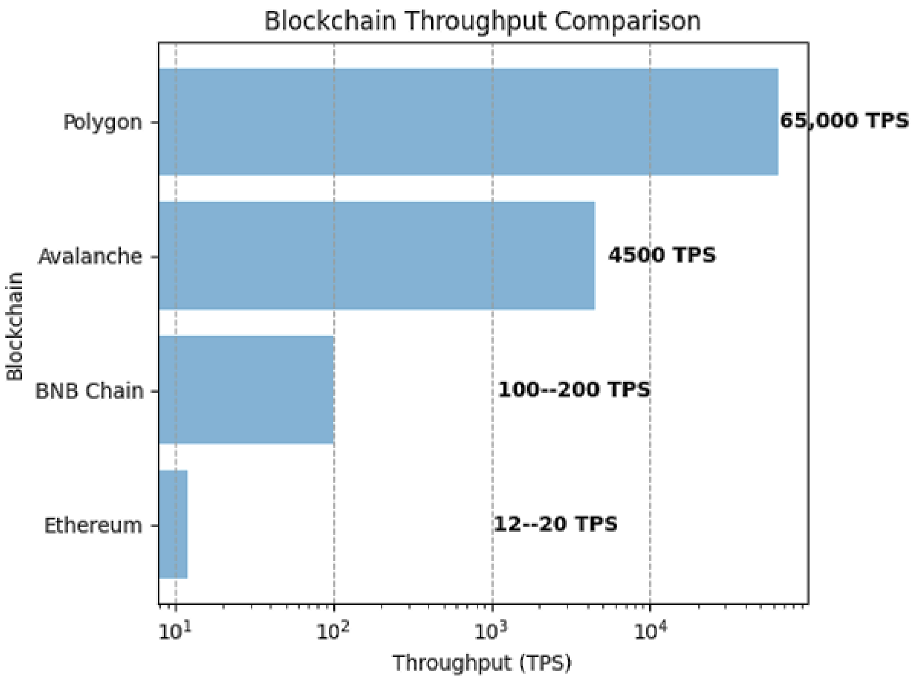

Figure 4.1 Blockchain throughput comparison

Communication Efficiency

Additionally, we assessed the effectiveness of communication throughout the data exchanges carried out at each stage. It is assumed that the operations of pairing, bilinear group computation, and hashing are performed on amounts of 160 bits.

Table 4.1: Communication cost of the proposed method

Item phase	Message Length (bits)	Round
The parameters Setup Phase	1120	2
Registration Phase	1440	2
Transfer Traffic Information Phase	1632	2

Figure 4.2 shows a line graph depicting the communication cost, measured in round trip time in milliseconds (ms), for various phases involved in setting up communication. The x-axis represents the message length in bits. The registration phase follows a similar trend, while the cost for the transfer traffic information phase increases but at a slower rate. The parameters setup phase has the lowest and constant communication cost irrespective of message length

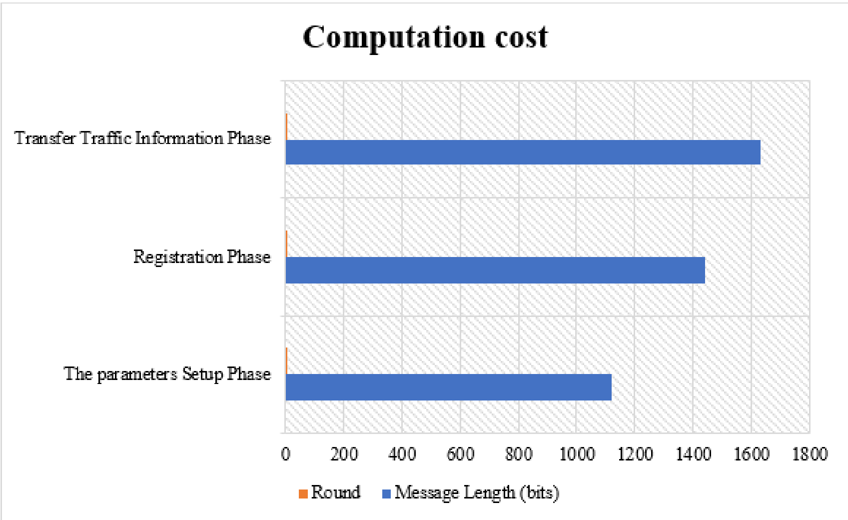

Figure 4.2 Comparison of communication cost

Network Lifetime

Table 4.2 depict the network life time values of proposed method and compared with existing technique. From table 4.2, it is clear that the proposed method outperformance in terms of network life time as compared to all other method.

Table 4.2 Network lifetime of proposed method

Metrics	Proposed method	Ethereum	Avalanche
Network life time	86	80	73
	88	83	76
	91	83	78
	94	85	83
	96	90	86

Figure 4.3 displays the NLT performance of the suggested strategies alongside established methods. If the NLT is greater, there will be no packet loss during delivery to the destination. The suggested solution achieves and network life time 96%. When comparing these rates, the current method produces much lower results for detecting NLT.

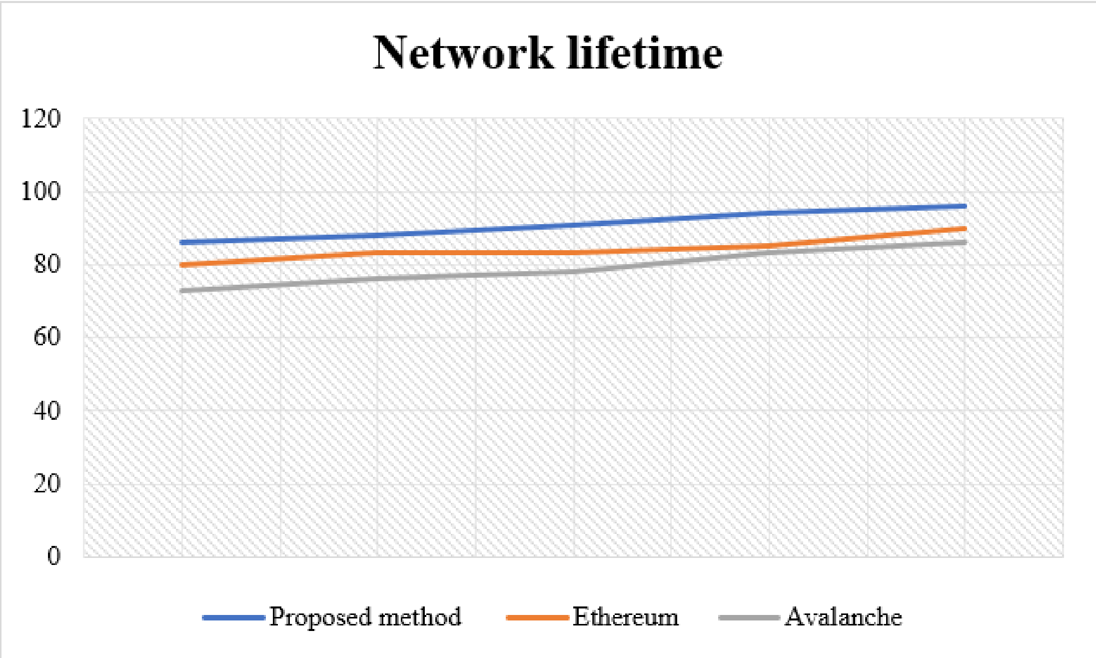

Figure 4.3 Network life time of proposed method

Table 4.3 depicts the PDR values of the proposed method and compares them with the existing technique.

Table 4.3 PDR of the proposed method

Metrics	Proposed method	Ethereum	Avalanche
PDR	88	78	70
	91	83	89
	95	82	85
	95	90	88
	97	94	92

PDR

Figure 4.4 shows the PDR graph of the proposed methodology together with existing methods. PDR demonstrates efficiency in routing data across network nodes. A higher Packet Delivery Ratio (PDR) results in better performance while transmitting data across mobile nodes without any loss. Therefore, it is clear that the proposed method gives superior performance as compared to all other methods.

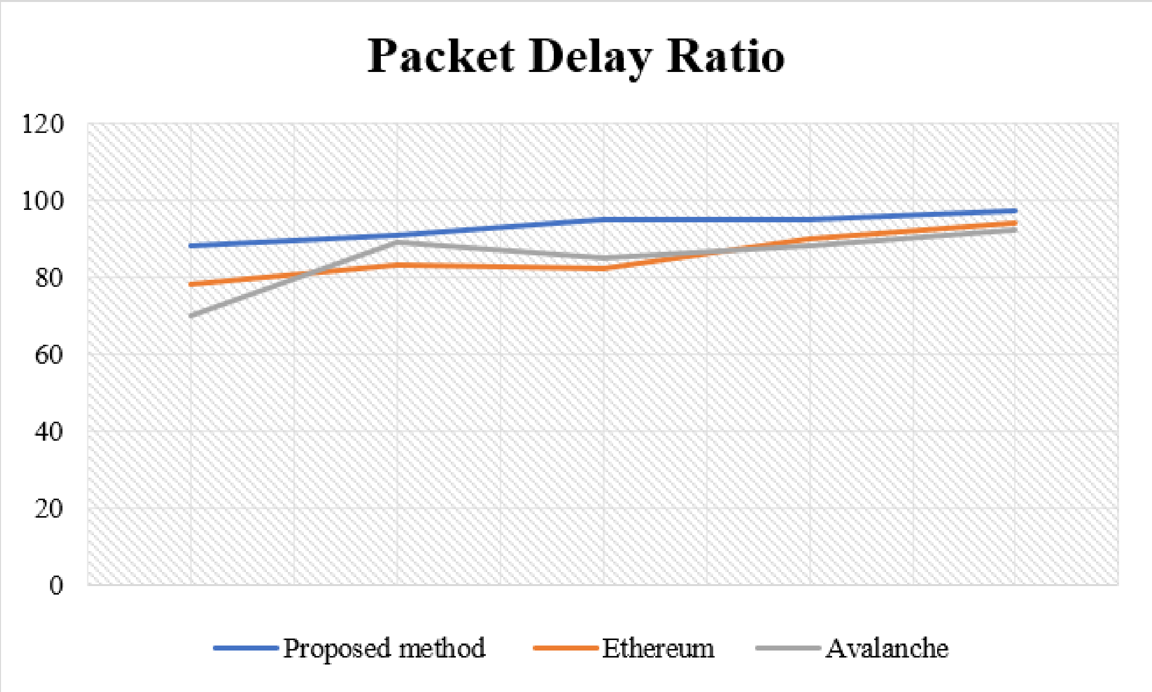

Figure 4.4 Packet delay ratio of the proposed technique

End-to-end delay

Table 4.4 depicts the end-to-end delay values of the proposed method and compared with the existing technique. From Table 4.4, it is clear that the proposed method is outperformance as compared to all other methods.

Table 4.4 End-to-end delay of the proposed method

Metrics	Proposed method	Ethereum	Avalanche
End-to-end delay	33	40	70
	39	52	75
	40	59	78
	50	60	80
	61	69	84

Figure 4.5 depicts the comparison between the proposed approach and the current method. The proposed method achieves a 61% delay reduction compared to the current approach. The latency of the proposed method is smaller compared to the current techniques used for the other nodes. Therefore, the suggested method is considered to provide excellent results in terms of secure data communication while also considering the delay.

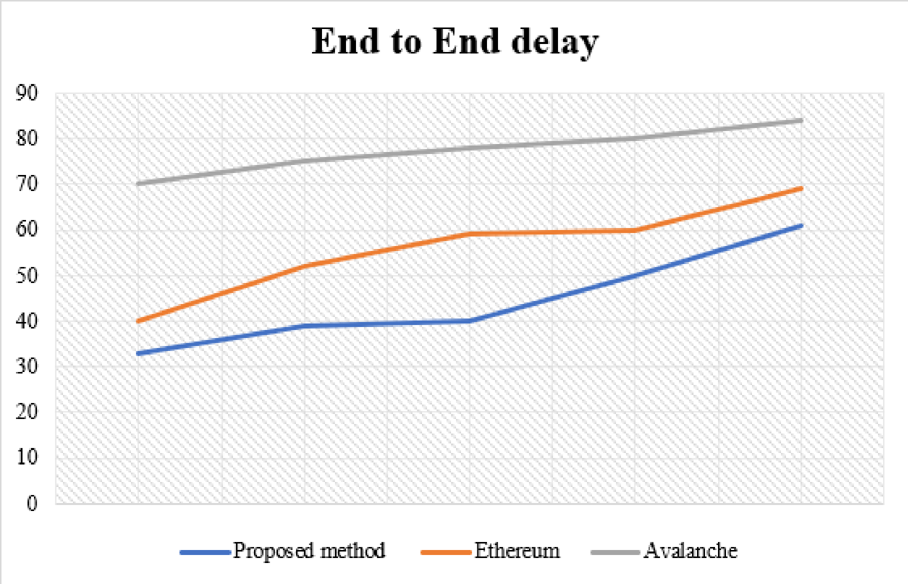

Figure 4.5 End to End of proposed method

5. Conclusions

The integration of IoT-enabled traffic management and Vehicle-to-Infrastructure (V2I) communication within Smart Transportation Systems (STS) represents a significant advancement in urban mobility and efficiency. The deployment of IoT sensors, connected devices, and intelligent traffic control systems has shown to be effective in dynamically adjusting traffic signals, providing real-time traffic information to drivers, and prioritizing emergency vehicles. Additionally, V2I communication has improved situational awareness for both vehicles and infrastructure, leading to more informed decision-making and quicker response to changing traffic conditions. The Smart Traffic Management System has been created by using several hardware components in the IoT. Traffic optimization is achieved by using an Internet of Things (IoT) technology to efficiently distribute different time periods to all traffic lights, taking into account the number of vehicles on the route. The adoption of the Smart Traffic Management System seeks to efficiently resolve the problem of traffic congestion and enable the redirection of cars at intersections. This research presents a very effective solution for the increasing traffic congestion in big metropolitan areas, which is continuously becoming worse and traditional methods are not sufficient in successfully managing the current traffic needs. The proposed V2B communication infrastructure, using blockchain technology and smart contracts, has immense potential to transform the transportation industry. By using the decentralized and secure attributes of blockchain technology, alongside the automation possibilities of smart contracts, we can create a transportation system that is more efficient, transparent, and secure. The use of IoT sensors enhances the system's cognitive capabilities and interconnectedness. In the future, it is advisable to concentrate more research on the actual implementation of this decentralized V2B architecture. This involves developing sophisticated contracts and communication protocols that provide seamless interactions between vehicles and the blockchain network. Furthermore, exploring novel approaches to include emerging technologies, such as artificial intelligence and machine learning, might enhance the effectiveness and productivity of V2B communication. By enhancing the V2B communication architecture and investigating the potential collaborations with state-of-the-art technologies, we have the potential to transform the transportation sector and open up new opportunities for enhanced efficiency, safety, and sustainability.

6. References

1. Tekler, Zeynep Duygu, Raymond Low, Chau Yuen, and Lucienne Blessing. "Plug-Mate: An IoT-based occupancy-driven plug load management system in smart buildings." Building and Environment 223 (2022): 109472."
2. Zhuang, Dian, Vincent JL Gan, Zeynep Duygu Tekler, Adrian Chong, Shuai Tian, and Xing Shi. "Data-driven predictive control for smart HVAC system in IoT-integrated buildings with time-series forecasting and reinforcement learning." Applied Energy 338 (2023): 120936.
3. Low, Raymond, Zeynep Duygu Tekler, and Lynette Cheah. "Predicting commercial vehicle parking duration using generative adversarial multiple imputation networks." Transportation Research Record 2674, no. 9 (2020): 820-831.
4. Kang, Hyoung Seok, Ju Yeon Lee, SangSu Choi, Hyun Kim, Jun Hee Park, Ji Yeon Son, Bo Hyun Kim, and Sang Do Noh. "Smart manufacturing: Past research, present findings, and future directions." International journal of precision engineering and manufacturing-green technology 3 (2016): 111-128.
5. Kandogan, Yener, and Scott D. Johnson. "Role of economic and political freedom in the emergence of global middle class." International Business Review 25, no. 3 (2016): 711-725.
6. How Many Cars Are in the U.S.? 2022. Available online: https://www.fool.com/the-ascent/research/car-ownership-statistics/
7. Zhang, Junping, Fei-Yue Wang, Kunfeng Wang, Wei-Hua Lin, Xin Xu, and Cheng Chen. "Data-driven intelligent transportation systems: A survey." IEEE Transactions on Intelligent Transportation Systems 12, o. 4 (2011): 1624-1639.
8. Oladimeji, Damilola, Khushi Gupta, Nuri Alperen Kose, Kubra Gundogan, Linqiang Ge, and Fan Liang. "Smart transportation: an overview of technologies and applications." Sensors 23, no. 8 (2023): 3880.
9. Al-Dweik, Arafat, Radu Muresan, Matthew Mayhew, and Mark Lieberman. "IoT-based multifunctional scalable real-time enhanced road side unit for intelligent transportation systems." In 2017 IEEE 30th Canadian conference on electrical and computer engineering (CCECE), pp. 1-6. IEEE, 2017.
10. Barth, D. The Bright Side of Sitting in Traffic: Crowdsourcing Road Congestion Data. Google Office Blog. 2009. Available online: https://googleblog.blogspot.com/2009/08/bright-side-of-sitting-in-traffic.html (accessed on 22 August 2022).
11. Arthurs, Peter, Lee Gillam, Paul Krause, Ning Wang, Kaushik Halder, and Alexandros Mouzakitis. "A taxonomy and survey of edge cloud computing for intelligent transportation systems and connected vehicles." IEEE Transactions on Intelligent Transportation Systems 23, no. 7 (2021): 6206-6221.
12. Gupta, Aniket, Sujata Kulkarni, Vaibhavi Jathar, Ved Sharma, and Naman Jain. "Smart car parking management system using IoT." Am. J. Sci. Eng. Technol 2, no. 4 (2017): 112-119.
13. Cha, Young-Jin, Wooram Choi, and Oral Büyüköztürk. "Deep learning-based crack damage detection using convolutional neural networks." Computer-Aided Civil and Infrastructure Engineering 32, no. 5 (2017): 361-378.
14. Chowdhury, Dipayan N., Nimish Agarwal, Arnab B. Laha, and Amrit Mukherjee. "A vehicle-to-vehicle communication system using Iot approach." In 2018 Second International Conference on Electronics, Communication and Aerospace Technology (ICECA), pp. 915-919. IEEE, 2018.

15. Azgomi, Hamid Fekri, and Mo Jamshidi. "A brief survey on smart community and smart transportation." In 2018 IEEE 30th international conference on tools with artificial intelligence (ICTAI), pp. 932-939. IEEE, 2018.
16. Pop, Mădălin-Dorin, Jitendra Pandey, and Velmani Ramasamy. "Future networks 2030: challenges in intelligent transportation systems." In 2020 8th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions)(ICRITO), pp. 898-902. IEEE, 2020.
17. Narayanan, Santhanakrishnan, Emmanouil Chaniotakis, and Constantinos Antoniou. "Shared autonomous vehicle services: A comprehensive review." Transportation Research Part C: Emerging Technologies 111 (2020): 255-293.
18. Frank, Anilloy, Yasser Salim Khamis Al Aamri, and Amer Zayegh. "IoT based smart traffic density control using image processing." In 2019 4th MEC International Conference on Big Data and Smart City (ICBDSC), pp. 1-4. IEEE, 2019.
19. Singh, Satbir, Baldev Singh, Baljit Singh, and Amitava Das. "Automatic vehicle counting for IoT based smart traffic management system for Indian urban settings." In 2019 4th International Conference on Internet of Things: Smart Innovation and Usages (IoT-SIU), pp. 1-6. IEEE, 2019.
20. https://blog.mantratec.com/how-iot-based-smart-traffic-management-system-optimizes-traffic.
21. Kanthavel, Dhaya, S. K. B. Sangeetha, and K. P. Keerthana. "An empirical study of vehicle to infrastructure communications-an intense learning of smart infrastructure for safety and mobility." International Journal of Intelligent Networks 2 (2021): 77-82.
22. Altuijary, Muath. "An Overview of Vehicle-to-Infrastructure Communication Technology." (2020).
23. Rashid, Muhammad, Muhammad Qadeer, Husnain Raza, Ifra Shabbir, Imran Rasool, and Nazir Ahmad Zafar. "Formal Modeling and Verification of IoT-based Smart Transport System using SPIN Model Checker." In 2024 IEEE 1st Karachi Section Humanitarian Technology Conference (KHI-HTC), pp. 1-6. IEEE, 2024.
24. Prakash, J., L. Murali, N. Manikandan, N. Nagaprasad, and Krishnaraj Ramaswamy. "A vehicular network based intelligent transport system for smart cities using machine learning algorithms." Scientific Reports 14, no. 1 (2024): 468.
25. Dui, Hongyan, Songru Zhang, Meng Liu, Xinghui Dong, and Guanghan Bai. "IoT-Enabled Real-Time Traffic Monitoring and Control Management for Intelligent Transportation Systems." IEEE Internet of Things Journal (2024).
26. Karthikeyan, H., and G. Usha. "A secured IoT-based intelligent transport system (IoT-ITS) framework based on cognitive science." Soft Computing (2023): 1-11.
27. Chowdhury, Abdullahi, Shahriar Kaisar, Mahbub E. Khoda, Ranesh Naha, Mohammad Ali Khoshkholghi, and Mahdi Aiash. "IoT-based emergency vehicle services in intelligent transportation system." Sensors 23, no. 11 (2023): 5324.
28. Sharma, Neerav, and Rahul D. Garg. "Real-time iot-based connected vehicle infrastructure for intelligent transportation safety." IEEE Transactions on Intelligent Transportation Systems (2023).
29. Chen, Zhong, C. B. Sivaparthipan, and BalaAnand Muthu. "IoT based smart and intelligent smart city energy optimization." Sustainable Energy Technologies and Assessments 49 (2022): 101724.
30. Mahmood, Khalid, Javed Ferzund, Muhammad Asad Saleem, Salman Shamshad, Ashok Kumar Das, and Youngho Park. "A provably secure mobile user authentication scheme for big data collection in IoT-enabled maritime intelligent transportation system." IEEE Transactions on Intelligent Transportation Systems 24, no. 2 (2022): 2411-2421.

31. Prasetyawan, Purwono, Slamet Samsugi, Agus Mulyanto, Muhammad Iqbal, and Rizky Prabowo. "A prototype of IoT-based smart system to support motorcyclists safety." In Journal of Physics: Conference Series, vol. 1810, no. 1, p. 012005. IOP Publishing, 2021.
32. Al-Ali, A. R., Raafat Aburukba, A. H. Riaz, Ahmad Al Nabulsi, D. Khan, S. Khan, and M. Amer. "Iot-based shared community transportation system using e-bikes." In 2021 5th International Conference on Smart Grid and Smart Cities (ICSGSC), pp. 61-65. IEEE, 2021.
33. Ayoub, Wael, Abed Ellatif Samhat, Mohamad Mroue, Hussein Joumaa, Fabienne Nouvel, and Jean-Christophe Prévotet. "Technology selection for iot-based smart transportation systems." In Vehicular Ad-hoc Networks for Smart Cities: Third International Workshop, 2019, pp. 19-29. Springer Singapore, 2020.
34. Dass, Prajnamaya, Sudip Misra, and Chandana Roy. "T-safe: Trustworthy service provisioning for IoT-based intelligent transport systems." IEEE Transactions on Vehicular Technology 69, no. 9 (2020): 9509-9517.
35. Sodhro, Ali Hassan, Mohammad S. Obaidat, Qammer H. Abbasi, Pasquale Pace, Sandeep Pirbhulal, Giancarlo Fortino, Muhammad Ali Imran, and Marwa Qaraqe. "Quality of service optimization in an IoT-driven intelligent transportation system." IEEE Wireless Communications 26, no. 6 (2019): 10-17.
36. Kumar Singh, Akhilesh, and Damodar Reddy Edla. "Efficient Road Infrastructure Management using IoT Sensor Fusion and V2V Interaction." International Journal of Computing and Digital Systems 16, no. 1 (2024): 1-11.
37. Naeem, Awad Bin, Abdul Majid Soomro, Hafiz Muhammad Saim, and Hassaan Malik. "Smart road management system for prioritized autonomous vehicles under vehicle-to-everything (V2X) communication." Multimedia Tools and Applications 83, no. 14 (2024): 41637-41654.
38. Hazarika, Anakhi, Nikumani Choudhury, Moustafa M. Nasralla, Sohaib Bin Altaf Khattak, and Ikram Ur Rehman. "Edge ML Technique for Smart Traffic Management in Intelligent Transportation Systems." IEEE Access (2024).
39. Alhaj, A., N. Zanoon, A. Alrabea, H. Alnatsheh, O. Jawabreh, M. Abu-Faraj, and B. J. Ali. "Improving the Smart Cities Traffic Management Systems using VANETs and IoT Features." Journal of Statistics Applications & Probability 12, no. 2 (2023): 405-414.
40. Liu, Chenchen, and Li Ke. "Cloud assisted Internet of things intelligent transportation system and the traffic control system in the smart city." Journal of Control and Decision 10, no. 2 (2023): 174-187.
41. Lilhore, Umesh Kumar, Agbotiname Lucky Imoize, Chun-Ta Li, Sarita Simaiya, Subhendu Kumar Pani, Nitin Goyal, Arun Kumar, and Cheng-Chi Lee. "Design and implementation of an ML and IoT based adaptive traffic-management system for smart cities." Sensors 22, no. 8 (2022): 2908.
42. Mohapatra, Hitesh, Amiya Kumar Rath, and Nibedan Panda. "IoT infrastructure for the accident avoidance: an approach of smart transportation." International Journal of Information Technology 14, no. 2 (2022): 761-768.
43. Kanthavel, Dhaya, S. K. B. Sangeetha, and K. P. Keerthana. "An empirical study of vehicle to infrastructure communications-an intense learning of smart infrastructure for safety and mobility." International Journal of Intelligent Networks 2 (2021): 77-82.

44. Elsagheer Mohamed, Samir A., and Khaled A. AlShalfan. "Intelligent traffic management system based on the internet of vehicles (IoV)." Journal of advanced transportation 2021, no. 1 (2021): 4037533.
45. Sheikh, Muhammad Sameer, Jun Liang, and Wensong Wang. "An improved automatic traffic incident detection technique using a vehicle to infrastructure communication." Journal of Advanced Transportation 2020, no. 1 (2020): 9139074.
46. Sherazi, Hafiz Husnain Raza, Zuhaib Ashfaq Khan, Razi Iqbal, Shahzad Rizwan, Muhammad Ali Imran, and Khalid Awan. "A heterogeneous IoV architecture for data forwarding in vehicle to infrastructure communication." Mobile Information Systems 2019, no. 1 (2019): 3101276.