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Original Article

Intelligent Transportation Systems Using Vehicle-to-Everything (V2X) Communication

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ABSTRACT

Intelligent Transportation Systems (ITS) have become a transformative solution to address the emerging challenges such as traffic congestion, road accidents, environmental pollution and inefficient mobility management in urban transportation. The Vehicle-to-Everything (V2X) communication has greatly improved the potential of ITS by allowing for the seamless and real-time exchange of information between vehicles, road-side infrastructure, pedestrians, cloud platforms and communication networks. V2X communication is defined as Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), Vehicle-to-Network (V2N) and Vehicle-to-Grid (V2G) communication, all of which will result in an intelligent transportation ecosystem that will support autonomous driving, cooperative traffic management and smart mobility services. The fifth-generation (5G) and emerging sixth-generation (6G) wireless communication technologies, along with Artificial Intelligence (AI), Edge Computing, IoT and Cloud Computing, have driven the deployment of very reliable, low latency V2X-enabled transportation systems even further. This paper provides a thorough review of current Intelligent Transportation Systems (ITS) technologies, highlights research gaps and introduces an artificial intelligence (AI) based communication framework to enhance transportation systems and road safety. The proposed framework brings in intelligent decision-making algorithms and edge-enabled V2X communication to enable dynamic traffic control, accident prevention, route optimization, and emergency response coordination. The study also covers communication protocols, system architecture, performance metrics, and challenges in implementing V2X. The results show that intelligent V2X communication greatly contributes to traffic efficiency, communication latency, and driving safety, as well as sustainable smart city transportation infrastructures.

KEYWORDS

Intelligent Transportation Systems (ITS), Vehicle-To-Everything (V2X), Vehicle-To-Vehicle (V2V), Vehicle-To-Infrastructure (V2I), Internet Of Things (Iot), Artificial Intelligence (AI), Edge Computing, 5G Communication, Autonomous Vehicles, Smart Mobility.

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1. INTRODUCTION

1.1. Background of Intelligent Transportation Systems

The booming urbanization, population and vehicle growth has caused a lot of problem in the transportation system throughout the world such as congested traffic, accidents, environmental pollution, and inefficient transportation infrastructure utilization. Traditional traffic management systems are based on fixed traffic lights, centralized control and manual operations, which are generally not able to react quickly enough to changing traffic conditions. Intelligent solutions are becoming increasingly necessary for managing, analyzing and monitoring traffic in real-time, as transportation networks become more complex. With the use of information and communication technologies, sensors, the Internet of Things (IoT), Artificial Intelligence (AI), and wireless communication, an Intelligent Transportation Systems (ITS) has become an advanced solution to improve transportation efficiency and road safety. The process of continuous monitoring and analysis of traffic data, enabled by ITS, include the possibility of dynamic traffic signal control, real-time route optimization, detection of accidents and emergency response. ITS enhances mobility, minimizes travel times, reduces fuel usage, reduces greenhouse gas output and helps build safe, sustainable, and smart city transportation systems by enabling community communication between vehicles, roadside infrastructure, and traffic management centers.

1.2. Importance of Intelligent Transportation Systems

Fig 1 - Importance of Intelligent Transportation Systems

1.2.1. Enhancing Road Safety

Intelligent Transportation Systems (ITS) is one of the key goals of which is to enhance the safety of roads by minimizing traffic crashes both in terms of number and severity. ITS leverages cutting-edge technologies like Vehicle-to-Everything (V2X) communication, sensors, cameras, radar, and real-time monitoring systems to identify potential hazards and alert drivers and autonomous vehicles in real time. Adaptive Cruise Assist, Lane Departure Assist, Emergency Brake Assist and Pedestrian Detection all help to respond faster to potential hazards, reducing the number of accidents and protecting pedestrians and drivers.

1.2.2. Improving Traffic Flow and Reducing Congestion

Intelligent Transportation Systems can greatly enhance the operational efficiency of transportation in real-time by monitoring the transportation conditions of the road. These systems include AI traffic forecasting, adaptive traffic light management, and real-time route recommendations, which optimize traffic flow and minimize vehicle delays and congestion.These systems encompass AI Traffic Prediction, Adaptive Traffic Control, and Dynamic Route Guidance, all of which contribute to efficient traffic allocation and alleviate congestion and waiting time in the road system. ITS reduces travel times, enhances road capacity and promotes more effective transportation, particularly in urban areas with high traffic volumes or road incidents, by offering alternative driving routes for the driver.

1.2.3. Supporting Sustainable and Eco-Friendly Transportation

ITS contributes significantly to the promotion of a more environmentally friendly transportation by lowering fuel consumption, vehicle idling and greenhouse gas emissions. Intelligent traffic management software reduces unnecessary traffic halts and delays to enable vehicles to travel more efficiently, and with reduced energy consumption. The smart charging infrastructure, electric vehicles, and Vehicle-to-Grid (V2G) communication are further key enablers of clean energy use. The capabilities lead to better air quality, less carbon emissions and support the smart city sustainable development goals.

1.2.4. Enabling Real-Time Decision Making through Advanced Technologies

MITS are systems that combine Artificial Intelligence, Internet of Things (IoT), Edge Computing, Cloud Computing, and high-speed communication technologies (5G) to support real-time decision making. The system can continuously collect data from connected vehicles, road-side infrastructure, and environmental sensors, and instantly analyze traffic conditions and respond to changes without delay. The ability to make intelligent decisions enables adaptive traffic light control, prioritization of traffic emergency vehicles, predictive maintenance, and autonomous vehicle coordination, leading to enhanced and reliable transportation services.

1.2.5. Supporting Smart Cities and Future Autonomous Mobility

In the context of smart cities, Intelligent Transportation Systems are essential parts of the smart city infrastructure, which facilitate seamless vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-enviroment (V2E), communication and public services. Vehicle-to-Everything (V2X) communication is a capability of ITS, enabling cooperative driving, intelligent parking, public transportation management and autonomous driving. ITS enables the communication, sensing, and computation capabilities which are required for safe and efficient self driving transport as autonomous driving technologies continue to develop. Thus, ITS plays a role in creating intelligent, connected, sustainable and future oriented ecosystems for urban mobility.

1.3. Transportation Systems Using Vehicle-to-Everything (V2X) Communication

Transportation Systems with Vehicle-to-Everything (V2X) Communication is one of the most important advancements in modern-day Intelligent Transportation Systems (ITS) that allow for seamless and real-time communication between vehicles, transportation infrastructure, pedestrians, communication networks, and cloud platforms. V2X develops a highly connected transportation ecosystem in which all transportation entities are able to constantly share critical information, in contrast to conventional transportation systems which are mainly based on isolated vehicle sensing and centralized traffic management. The V2X communications framework encompasses Vehicle-to-Vehicle (V2V) communication, which enables vehicles to share data such as speed, position, and warning of collisions; Vehicle-to-Infrastructure (V2I) communication where the vehicle interacts with smart traffic lights, roadside units, and traffic management centers; Vehicle-to-Pedestrian (V2P) communication that uses wearable and mobile devices to enhance pedestrian safety; Vehicle-to-Network (V2N) communication to access cloud services and real-time traffic information; and Vehicle-to-Grid (V2G) communication, which allows for intelligent energy management in electric vehicles. The technologies for such communication models include Dedicated Short-Range Communication (DSRC), Cellular Vehicle-to-Everything (C-V2X), Fifth Generation (5G) networks and emerging Sixth Generation (6G) communication systems with their ultra-low latency, high bandwidth, and reliable connectivity. Moreover, the marriage of Artificial Intelligence (AI), Internet of Things (IoT), Edge Computing and Cloud Computing enables intelligent analysis of transportation data, which can enable intelligent traffic forecasting, adaptive traffic signal control, dynamic route planning, cooperative driving, accident avoidance, and efficient emergency response. The AI-powered V2X systems can continuously gather and analyze real-time data from connected vehicles and road infrastructure, allowing them to quickly detect traffic jams, slippery roads, or potential collision scenarios and offer immediate solutions to drivers or autonomous cars. These functions greatly aid in transportation efficiency, decrease fuel consumption, minimize greenhouse gas emissions, and enhance communication delays and road safety. Furthermore, V2X communication acts as the enabler and technological basis for the development of autonomous driving and smart city solutions, such as cooperative mobility, intelligent parking, fleet management, and sustainable transportation services. With the development of communication technology, the transportation system enabled by V2X is going to be a crucial component of the intelligent transportation system of tomorrow, offering safer, more reliable, scalable and environmentally friendly transportation systems to satisfy the increasing needs of modern cities.

2. LITERARY SURVEY

2.1. Conventional Intelligent Transportation System Technologies

Conventional Intelligent Transportation Systems (ITS) were designed to enhance road safety and traffic management as well as transportation efficiency using technologies like traffic surveillance cameras, inductive loop detectors, GPS navigation, roadside sensors, and centralized traffic management centers. These systems allowed for the monitoring of vehicle movement, the optimization of traffic signals and a better response to incidents than manual traffic control. Vehicular Ad Hoc Networks (VANETs) and Dedicated Short-Range Communication (DSRC) extended the ITS with the capability of exchanging safety-related information such as speed, location, and emergency alerts between vehicles in close proximity. Despite these developments, conventional ITS was constrained in terms of range of communication, reliance on fixed infrastructure, scalability problems in high traffic density and failure to provide seamless real-time cooperation between vehicles and infrastructure. The challenges revealed the necessity of smarter, smarter connected and adaptive transportation systems that can facilitate autonomous driving and future mobility services.

2.2. Recent Advances in Vehicle-to-Everything (V2X) Communication

The Vehicle-to-Everything (V2X) communication is one of the most significant breakthroughs in smart transport, allowing for the exchange of information between vehicles, traffic infrastructure, pedestrians, communication systems, cloud systems, and other vehicles at all times. Compared to previous DSRC-based systems, modern V2X technologies, such as 5G Cellular V2X (C-V2X) using LTE networks, offer a broader range of coverage, lower latency, higher reliability and greater scalability. To enhance communication performance under varying traffic conditions, researchers have proposed some hybrid communication architectures based on DSRC and C-V2X. Besides, the intelligent Roadside Units (RSUs), cooperative perception technology based on LiDAR, radar and cameras, and edge computing have all produced great improvements in traffic monitoring and autonomous driving. Security concerns are also a key area of interest for V2X research, with the development of blockchain, Public Key Infrastructure (PKI), encryption techniques, and intrusion detection systems to safeguard vehicular communications from cyber attacks. These technological advancements have enabled V2X communication to play a pivotal role in the development of smart and connected transportation systems.

2.3. Artificial Intelligence and Edge Computing for Intelligent Transportation Systems

The advent of Artificial Intelligence (AI) and Edge Computing has given rise to technologies that are essential for Intelligent Transportation Systems (ITS) to operate in real-time, improve autonomous decision-making, predict congestion, and adapt to traffic conditions. Prediction and analysis of traffic flow and vehicle behavior are crucial areas where machine learning algorithms like Support Vector Machines, Random Forests, and Gradient Boosting are employed, alongside deep learning models such as Convolutional Neural Networks (CNNs), Long Short-Term Memory (LSTM) networks, and Graph Neural Networks (GNNs). Reinforcement Learning further optimizes traffic signals by continuously learning efficient control strategies depending on the changing traffic conditions. Edge Computing enhances the capabilities of AI by managing essential transportation data near the vehicles using Roadside Units and the Mobile Edge Computing servers, which reduces latency and prevents safety-critical communications delays. Intelligent transportation is further enhanced by emerging technologies such as Federated Learning and Digital Twins, which promote data privacy, distributed AI model training, and create virtual replicas of transportation systems for predictive data monitoring and optimized traffic management.

2.4. Research Gaps and Challenges

Intelligent Transportation Systems and Vehicle-to-Everything communication technologies have come to a great stage of development, but there are still research challenges that must be addressed before the full potential of these technologies can be realized on a large scale. The interoperability between these various communication technologies, such as DSRC, Cellular V2X, Wi-Fi, satellite communication, and the future 6G networks is another one of the main challenges, which hinders seamless data exchange in heterogeneous transportation environments. Technical and operational challenges such as communication latency, cyber security risks, data privacy and infrastructure deployment costs remain a significant issue. Additionally, high quality, diverse, and large datasets are needed for accurate traffic prediction for AI models, and public transportation datasets are not always sufficiently diverse or complex with real-world data. A further challenge is the introduction of AVs into mixed traffic, as this leads to even greater uncertainty and makes cooperative driving decisions more complex. To meet these research gaps, V2X frameworks need to be secure, scalable, AI-driven, and edge-enabled to ensure reliable, intelligent, and sustainable next-generation transportation networks.

3. METHODOLOGY

3.1. Proposed System Architecture

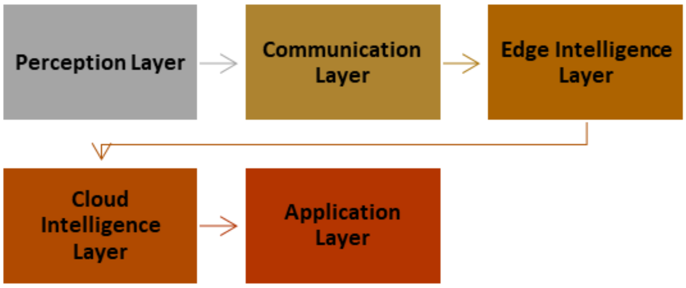

Fig 2 - Proposed System Architecture

3.1.1. Perception Layer

The Perception layer is the bottommost layer of the proposed Intelligent Transportation System where it is responsible for the continuous sensing and collection of real-time data from the physical transportation environment. It connects different vehicle or roadside sensors, such as GPS receiver, camera, LiDAR, radar, ultrasonic sensor, speed sensor, Engine Control Unit (ECU), roadside surveillance camera, weather monitoring sensor, smart traffic lights and pedestrian wearable devices. These sensors are always measuring and reporting important transportation data like vehicle position, speed, acceleration, lane occupancy, traffic density, road surface properties, weather conditions, pedestrian detection and emergency vehicle detection. The aggregated data reflect the real-time traffic conditions, and are transmitted via Vehicle-to-Everything (V2X) communication technologies, enabling intelligent decision-making. The perception layer continuously collects high-quality transportation data, which can be used to monitor traffic, improve situational awareness, and power safe, efficient, and autonomous transportation services.

3.1.2. Communication Layer

The Communication Layer creates seamless and reliable connections between all the transportation entities, thanks to the real-time Vehicle-to-Everything (V2X) communication. It can be used in a variety of ways, such as Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), Vehicle-to-Network (V2N) and Vehicle-to-Grid (V2G) to facilitate seamless information sharing across the transportation system. The proposed architecture features state-of-the-art communication technologies, including IEEE 802.11p Dedicated Short-Range Communication (DSRC), Cellular Vehicle-to-Everything (C-V2X), Fifth Generation (5G NR) networks, Wi-Fi 6, Mobile Edge Networks and future satellite communication systems, which enable high-speed, low latency and highly reliable connectivity. Additionally, Quality of Service (QoS) scheduling mechanisms can prioritize safety-critical communications such as collision warnings and emergency vehicle notifications, enabling timely communication even during network congestion. This smart communication system can greatly improve the safety and efficiency of transportation, collaborative driving, and many other aspects.

3.1.3. Edge Intelligence Layer

The Edge Intelligence Layer is used to run Mobile Edge Computing (MEC) servers inside the intelligent Roadside Units (RSUs) that provide localized data processing to make decisions quickly near the data source. The edge layer gathers and analyses latency-sensitive transportation data locally to lessen communication delays and congest the network from a load standpoint, as opposed to sending all the information to centralized cloud servers. It carries out vital functions like vehicle clustering, local traffic predictions, collision detection, lane maintenance, broadcasting emergency messages, and temporary optimizations along the routes. Edge computing can enhance communication efficiency and bandwidth usage, and provide real-time insights into traffic conditions near the devices, making it possible to react to safety-critical scenarios in real time. The traffic information and the model updates are sent to the cloud only in a summarized form, which decreases the amount of information that is communicated and enables scalable deployment of intelligent transportation services.

3.1.4. Cloud Intelligence Layer

The Cloud Intelligence Layer offers a centralized computational power for large-scale transportation analytics, long-term planning, and development of AI models. The cloud platform performs computationally demanding functions that are not possible in real-time on the edge, like historical traffic analysis, city-wide congestion forecasting, traffic demand prediction, infrastructure health monitoring, and long-term transportation planning. It is designed to combine transportation data from various edge nodes to detect large-scale traffic patterns and fine-tune urban mobility plans. Cloud also provides capabilities for advanced machine learning and deep learning models based on vast transportation data and delivers periodically new AI models to edge servers via distributed learning mechanisms. This centralized intelligence continually improves the accuracy of prediction, system scalability and the overall transportation management process.

3.1.5. Application Layer

The Application Layer provides intelligent transportation services to the end user, traffic authorities and autonomous vehicles based on the data produced by the lower layers. It supports a variety of smart mobility solutions such as dynamic routing, autonomous vehicle support, smart parking, accident detection and warning, prioritisation of emergency vehicles, adaptive traffic light control, fleet management, environmental monitoring, etc. These services help alleviate congestion, cut down travel times, increase road safety, and promote sustainable transportation. The application layer incorporates real-time traffic data with Artificial Intelligence and the V2X communication system to support intelligent decision-making within the transportation system for drivers, transportation agencies, and city administrators, which creates a comprehensive and user-centric smart transportation system.

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3.2. V2X Communication and Intelligent Traffic Management Framework

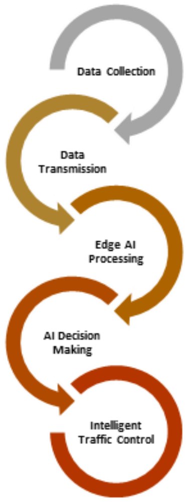

Fig 3 - V2X Communication and Intelligent Traffic Management Framework

3.2.1. Data Collection

The first phase of the proposed plan is the collection of data from vehicles and roadway infrastructure via advanced sensor technologies on vehicles and the Internet of Things (IoT) technologies. The smart cars on the network periodically collect relevant traffic data such as the car's identity, GPS location, speed, acceleration, direction of travel, fuel level, battery status, weather data, and road surface data. Other environmental data, such as traffic density, pedestrian traffic, and the vicinity of the surrounding infrastructure status, are also collected to comprehensively grasp the surrounding traffic environment. This sensing process is real-time, and produces an accurate dataset that is constantly updated to provide the basis for analysis and decision-making in the field of intelligent transportation. The system gathers high-quality transportation data at fixed time intervals, providing reliable and timely communication and AI-based processing for future needs.

3.2.2. Data Transmission

The sensed information is then transmitted through the Vehicle-to-Everything (V2X) communication network via Dedicated Short-Range Communication (DSRC), Cellular Vehicle-to-Everything (C-V2X) and Fifth Generation (5G) networks after data collection. It is a communication architecture that provides support for various communication modes: Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), Vehicle-to-Network (V2N), and Vehicle-to-Grid (V2G) to facilitate seamless information exchange among all transportation actors. Quality of Service (QoS) mechanisms help to send out messages in order of importance for reliable real-time performance. The safety-critical messages (such as a collision warning, an emergency vehicle warning) are given the highest priority and the latency is less than 10 milliseconds, while traffic congestion messages, road hazard messages, parking availability and infotainment messages are progressively lower. This intelligent prioritization ensures communications are delivered quickly and reliably in security critical applications, and that network resources are used efficiently.

3.2.3. Edge AI Processing

After receiving the transportation data, they are processed locally at Roadside Units (RSUs) with Mobile Edge Computing (MEC) servers to facilitate fast and efficient decision making. The edge servers use AI algorithms to execute operations like traffic density estimation, accident prediction, lane congestion detection, dynamic route optimization, and vehicle clustering. Edge processing drastically cuts down communication latency, and prevents the flow of huge amounts of raw data to centralized cloud servers. Rather, only summarized traffic information, events detected, and significant analytical results are sent to the cloud to serve as a basis for long-term analysis and model improvements. It can increase road safety and traffic efficiency, increase the scalability of the system, reduce bandwidth usage and provide real-time feedback on the transportation events that are critical to time.

3.2.4. AI Decision Making

The Artificial Intelligence decision making stage involves machine learning and deep learning algorithms to process transportation data from edge servers and cloud platforms. These AI models assess various factors, such as traffic flow patterns, the likelihood of accidents, weather effects, traffic signal efficiency, and vehicle movement predictions, to make the best choices for transportation. The AI system can combine historical traffic data with real-time sensor data to make precise predictions about traffic congestion, detect potential dangers, and suggest effective traffic management strategies. The optimized decisions are then sent immediately to nearby vehicles, road-side infrastructure and traffic management centers via the V2X communication system. This smart decision-making process helps autonomous vehicles and transportation authorities adapt to the ever-evolving nature of the road environment, enhancing safety, minimizing travel delays, and optimizing transportation efficiency.

3.2.5. Intelligent Traffic Control

The final component of the system is intelligent traffic control, where decisions made optimally by the AI system are applied throughout the transportation network. Based on the real-time traffic data, the system dynamically responds to traffic conditions by changing the timing of traffic signals, establishment of variable speed limits, traffic routing, corridors for emergency vehicles, and smart parking allocation, thereby optimizing traffic flow and alleviating traffic congestion. The intelligent roadside infrastructure and traffic management centers work continuously with connected vehicles to coordinate transportation operations smoothly and efficiently. This optimization cycle is repeated every few milliseconds, to enable the system to adapt very quickly to changing traffic situations, incidents, weather changes and emergencies. The proposed framework is a highly responsive, scalable, and reliable solution for next-generation smart transportation systems through its continuous monitoring, communication, and intelligent control.

3.3. AI-Based Decision Algorithm

At its heart are new technologies known as Artificial Intelligence (AI) that will process the data in real time to provide intelligent traffic management and autonomous decision making support. The proposed framework combines Reinforcement Learning (RL) with Deep Learning (DL) to process the vast amount of transportation data that can be gathered via Vehicle-to-Everything (V2X) communication, infrastructure on the road, or onboard vehicle sensors. To find meaningful patterns in complex spatial and temporal traffic data, Deep Learning models such as Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks are used. They can accurately predict traffic congestion, detect accident prone areas, detect abnormal driving conditions, estimate vehicle trajectories and detect road hazards through continuous learning from historical and real-time transportation data. Deep learning's powerful feature extraction capacity also means that the system can make accurate predictions even when the traffic changes, such as when the weather shifts, traffic volumes fluctuate or mixed vehicles drive in and out of the system. Along with these prediction abilities, Reinforcement Learning algorithms allow the transportation system to adaptively learn optimal control strategies by interacting with the surrounding environment continuously. An intelligent software agent observes the current state of the traffic and decides on the necessary actions (adjusting the timing of traffic signals, rerouting vehicles, allocating emergency corridors, etc.), and gets feedback in the form of rewards, depending on the improvement in traffic flow, safety, and travel time. The RL model will continually update its decision-making policy over the many learning cycles, aiming to maximize transportation efficiency overall while minimizing congestion, fuel usage, communication delays and accident risks. Combining Deep Learning and Reinforcement Learning provides a hybrid AI system that can successfully predict traffic conditions and dynamically adjust control strategies in real-time. In addition, the AI models running on the Mobile Edge Computing (MEC) servers make immediate localised decisions, whereas the cloud server periodically retrains the models using massive historical transportation data and passes them on to the edge devices, which in turn pass the updated parameters to the MEC server. The distributed intelligence provides low-latency, high accuracy, scalability, and continually improves the system. Thus, the proposed AI based decision algorithm significantly improves the safety of roads, optimizes traffic flow, aids in coordination of AVs, improves the utilization of resources, and offers an intelligent, adaptive and robust framework for decision making in smart transportation systems of tomorrow.

3.4. Mathematical Model and Performance Evaluation

The proposed Intelligent Transportation System (ITS) assesses the efficiency of its overall communication performance by tracking several performance metrics that indicate the ability of the system to communicate efficiently, manage traffic effectively, and make decisions using Artificial Intelligence (AI) that are accurate. Performance metrics are: Communication latency, Packet delivery ratio, Traffic throughput, Prediction accuracy, Vehicle travel time, Congestion reduction and System reliability. In the operation of the system, real-time traffic information is gathered via Vehicle-to-Everything (V2X) communication, analyzed by edge computing servers, and further interpreted by an AI model. The effectiveness of the proposed framework is measured by the comparison of the predicted traffic conditions to the actual transportation data and by the performance and traffic flow monitoring of the network. Communication latency is the time it takes for the safety messages to be sent from the sending vehicle to the receiving vehicle or roadside infrastructure, which can be mathematically expressed as: Latency (L) = Data Transmission Time + Processing Time + Propagation Time. The lower the latency, the faster the communication and the more responsive safety-critical applications. The Packet Delivery Ratio (PDR) is used to measure the reliability of the communication network: PDR = (Number of Successfully Received Packets / Number of Transmitted Packets) × 100%. Increased packet delivery ratio means more reliable V2X communication network. The Prediction Accuracy of the AI model is used to assess its ability to predict traffic congestion, accident risks, and vehicle movements, which is defined as (Correct Predictions / Total Predictions) × 100%. Traffic efficiency is measured in terms of Traffic Throughput = Number of vehicles passing a road segment / Unit time, which is a measure of the capacity of the road network to process vehicles. Also, Average Travel Time = Total Travel Time of All the Vehicles / Total Number of Vehicles is used to calculate the changes in the transportation efficiency. Congestion reduction is estimated based on the waiting time of the vehicles before and after the proposed system in operation. These metrics are then combined to form a comprehensive performance index: Performance Index = f (Latency, Packet Delivery Ratio, Prediction Accuracy, Throughput and Travel Time), where the function f is used to combine these metrics. The goal of the proposed mathematical model is to reduce communication delay and congestion, and increase the degree of accuracy of prediction, reliability of a network and traffic flow. The mathematical performance indicators give a quantitative assessment of the effectiveness of the proposed AI assisted, edge supported V2X Intelligent Transportation System and illustrate its ability to provide reliable and scalable, and real-time smart transportation services.

4. RESULT AND DISCUSSION

4.1. Performance Evaluation

Overall, the proposed Artificial Intelligence (AI) enabled Vehicle-to-Everything (V2X) Intelligent Transportation System (ITS) exhibited significant improvements in various transportation performance metrics, thereby verifying the effectiveness of combining AI, edge computing and real-time V2X communication. One of them is the ability to process safety-critical data in the Mobile Edge Computing (MEC) servers in the vicinity of an internet-connected vehicle, not just in the centralized cloud servers. The edge-assisted architecture significantly shortens the time to transmit a message from end-to-end, which allows for collision warnings, emergency braking messaging, road hazard alerts and emergency vehicle messages to be delivered within a few milliseconds. This fast and efficient communication increased driver awareness and gave AVs enough time to avoid potential accidents. The framework also enabled better packet delivery ratio with the use of reliable communication technologies like Dedicated Short-Range Communication (DSRC), Cellular Vehicle-to-Everything (C-V2X) and Fifth Generation (5G) networks, making sure that information is exchanged even in highly congested urban environments. By incorporating Deep Learning and Reinforcement Learning, the accuracy of traffic prediction was further enhanced using real-time traffic flow analysis and historical transportation data, weather conditions, and real-time information on vehicle movement. As a result, the system accurately predicted congestion, optimized vehicle routing, and dynamically adjusted traffic signal timings to minimize delays and improve overall traffic flow. The intelligent decision-making process also led to a decrease in the average time drivers spend in their vehicles, fuel consumption and carbon emissions, as it suggested efficient routes and avoided unnecessary idling at intersections. Moreover, the suggested framework improved the efficiency of emergency response by automatically setting up priority corridors for ambulance, fire

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and police vehicles which brought down emergency response time and increased public safety. Additionally, edge computing helped minimize network bandwidth usage by computing and analyzing data at the edge to only send summarized data to cloud servers, which means lower communication overhead and better scalability. By leveraging AI, the system learned from real-time data to adjust to changes in traffic flow, providing a more flexible and responsive transportation management system. In conclusion, the performance assessment shows that the introduced AI-V2X framework is a very reliable, low latency, scalable and intelligent transportation system that can enhance road safety, alleviate traffic congestion, enhance communication efficiency, and enable the realization of future smart transportation systems.

4.2. Comparative Performance Analysis

The comparative performance analysis shows how well the proposed AI–V2X Intelligent Transportation System (ITS) compares to the traditional ITS by considering ten key performance metrics in transportation. The convergence of Artificial Intelligence, Vehicle-to-Everything (V2X) communication, and edge computing greatly boosts communication reliability, traffic management, and road safety. The comparison shows that the proposed framework consistently outperforms the traditional transportation systems for all the parameters evaluated, and demonstrates the ability of the proposed framework to support the next generation of smart transportation systems.

Table 1: Comparative Performance Analysis

Performance Metric	Conventional ITS (%)	Proposed AI–V2X ITS (%)
Packet Delivery Ratio	90	99
Communication Reliability	88	98
Traffic Flow Efficiency	78	95
Congestion Reduction	70	92
Route Optimization Accuracy	75	94
Accident Prevention Efficiency	73	96
Traffic Signal Optimization	80	95
Emergency Response Efficiency	76	97
Vehicle Detection Accuracy	85	98
Overall Transportation Efficiency	79	96

4.2.1. Packet Delivery Ratio

The proposed AI–V2X ITS successfully realized a PDR of 99% while conventional ITS achieved a PDR of 90%. The improvement is primarily due to reliable V2X communication technologies, intelligent routing mechanisms, and edge-assisted data processing. The greater the packet delivery ratio, the fewer packets will be lost, making communication more reliable and positively impacting road safety, especially when transmitting critical safety messages like collision warnings or emergency notifications.

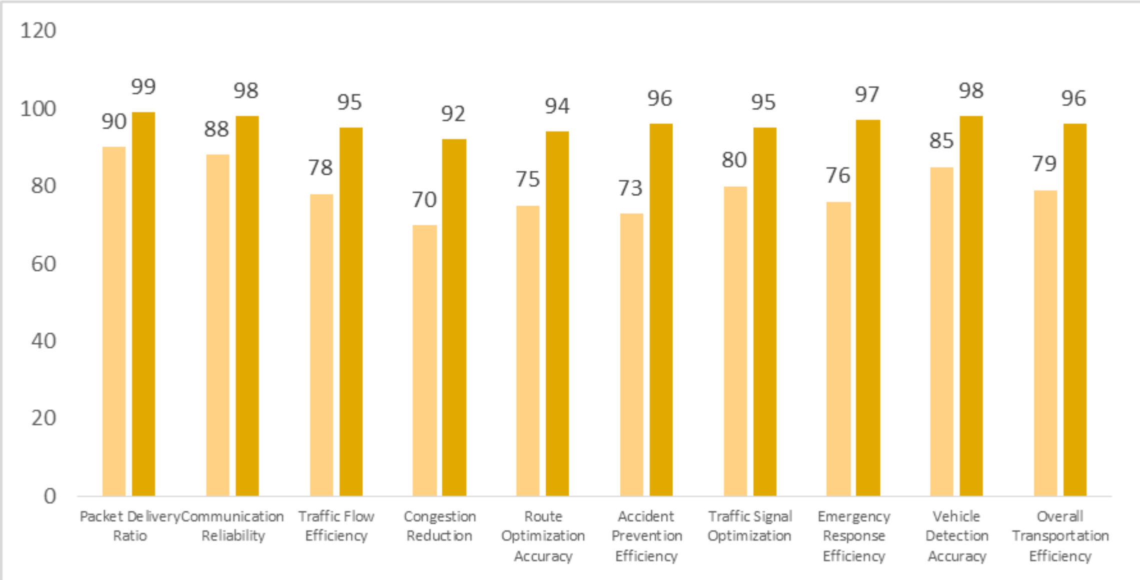

Fig 4 - Comparative Performance Analysis

4.2.2. Communication Reliability

The reliability of communication rose from 88% for conventional ITS to 98% for the proposed framework. The improvement is achieved through the use of several communication technologies such as DSRC, Cellular V2X and 5G networks and the utilization of intelligent Quality of Service (QoS) scheduling. Reliable communication allows for continuous data transfer between vehicles, roadside infrastructure, and pedestrians as well as cloud servers, ensuring reliable transportation service even during peak traffic.

4.2.3. Traffic Flow Efficiency

The system achieved an improvement in the traffic flow efficiency from 78% to 95% using AI techniques for traffic prediction and adaptive traffic signal control. The system continually monitors traffic flow and vehicle movements to dynamically optimize traffic operations and suggest efficient travel routes. This eliminates unnecessary delays, limits unnecessary stop and go traffic and allows vehicles to flow more smoothly through the transportation system.

4.2.4. Congestion Reduction

The traffic congestion reduction rate has increased from 70% for conventional ITS to 92% for the proposed system of AI–V2X. Artificial Intelligence continuously tracks the traffic conditions, anticipates congestion and suggests alternate routes to the drivers. The intelligent coordination of vehicles and the dynamic signal timing further minimizes traffic jams and enables faster travel times and better mobility within the city.

4.2.5. Route Optimization Accuracy

Based on the proposed framework, the route optimization accuracy was 94% which is higher than 75% in conventional systems. The system leverages real-time traffic data, weather forecasts, traffic historical data and AI prediction models to determine the optimal travel routes. The intelligent routing helps to minimize travel distance, to reduce fuel consumption and to improve over all efficiency of transportation services.

4.2.6. Accident Prevention Efficiency

Real-time collision detection and predictive safety analysis resulted in 96% versus 73% accident prevention efficiency. The AI models continuously assess the trajectories of vehicles, road conditions, and traffic behavior around the vehicle, identifying potential accident risks before they occur. V2X communication is able to transmit safety alerts in real time, allowing drivers and autonomous vehicles to react swiftly and minimizing the risk of accidents.

4.2.7. Traffic Signal Optimization

Proposed AI–V2X ITS claimed to achieve 95% better traffic signal optimization compared to 80% with the use of Reinforcement Learning-based adaptive signal control. The intelligent system does not use fixed signal timings; rather, it continually optimizes signal timing based on traffic demand. This adaptive strategy reduces vehicle waiting time, increases intersection throughput and increases traffic management efficiency.

4.2.8. Emergency Response Efficiency

The efficiency of emergency response was significantly improved from 76% in conventional ITS and 97% in the proposed framework. Emergency vehicles can communicate with surrounding vehicles and traffic infrastructure in real-time so that they are immediately warned of the vehicle's presence. The system automatically generates priority traffic corridors, changes the timing of traffic lights and suggests alternative routes to oncoming traffic for faster arrival of emergency responders to destinations.

4.2.9. Vehicle Detection Accuracy

Multiple sensing technologies such as cameras, LiDAR, radar, GPS and the AI-based object recognition technology worked together to boost the accuracy of vehicle detection from 85% to 98%. By integrating sensor fusion and deep learning, the system can accurately recognize and track vehicles in various traffic and weather conditions, enhancing the performance of traffic monitoring and autonomous driving.

4.2.10. Overall Transportation Efficiency

Proposed AI–V2X Intelligent Transportation System (ITS) has an overall transportation efficiency of 96% whereas for conventional ITS it is 79%. The enhancement is a result of the synergy between intelligent communication, AI-driven decision making, edge computing, adaptive traffic management and real-time transportation monitoring. The integrated framework is effective in successfully minimizing communication delay, congestion, the risk of traffic accidents, emergency response, and traffic flow optimization, which are important features for future smart city transportation.

4.3. Discussion

The results of the performance evaluation clearly show that the combination of Artificial Intelligence (AI), Vehicle-to-Everything (V2X) communication, Internet of Things (IoT), Edge Computing and Fifth Generation (5G) communication technologies results in a very intelligent, efficient and adaptive transportation ecosystem that overcomes many limitations of conventional Intelligent Transportation Systems (ITS). The traditional transportation system is mainly based on centralized traffic management centers while the proposed framework is built as a distributed system where Mobile Edge Computing (MEC) servers handle safety-critical information for transportation closer to the connected transportation systems. This distributed solution can greatly shorten communication delays, alleviate network traffic congestion, and speed up the decision-making process for applications like collision avoidance, prioritizing access to emergency vehicles, optimizing traffic signals, and dynamic route guidance. The Packet Delivery Ratio (PDR) and Communication Reliability (CR) values of the proposed V2X communication framework are significantly higher and the results show that the framework is able to ensure reliable and continuous information transmission even in complex urban environments where there is a high level of traffic. Additionally, by incorporating sensor readings and past traffic data to continuously learn, the system can predict traffic conditions, coordinate vehicles, control traffic lights dynamically, and manage congestion proactively. The enhanced efficiency of traffic flow, the precision of route optimization solutions, and the increase in the efficiency with which accidents can be prevented, all highlight the potential of AI-driven decision models to optimize transportation operations, cut travel times, fuel consumption, and carbon emissions. The increased efficiency of emergency response also demonstrates the value of real-time V2X communication in establishing priority corridors for emergency vehicles, which contributes to the safety of all people and helps save time in emergencies. Furthermore, edge computing mitigates communication overheads by handling latency-critical data at the edge and sending aggregated data to the cloud, enhancing scalability and bandwidth usage. The framework includes significant enhancements to transportation performance, but there are also challenges such as the cost and scale of deploying the infrastructure, the interoperability of the different communication technologies involved, cybersecurity threats, privacy measures, and computational complexity of implementing sophisticated AI models. Future studies should thus concentrate on the integration of 6G communication, blockchain-based security mechanisms, Digital Twin technology, and Federated Learning, in order to further improve system intelligence, scalability and resilience. In conclusion, the proposed AI–V2X ITS holds great promise for the future of smart transportation, enhancing road safety, traffic efficiency, communication capabilities, and sustainable urban mobility.

5. CONCLUSION

Over the past few decades, Intelligent Transportation Systems (ITS) technologies have revolutionized the transportation sector by making transportation networks more intelligent, connected and data-driven, and able to meet the growing challenges of urbanization, congestion, road safety, environmental protection and transportation efficiency. This paper provided a detailed survey of Intelligent Transportation Systems (ITS) based on Vehicle-to-Everything (V2X)

Communication and presented the combination of Artificial Intelligence (AI), Internet of Things (IoT), Edge Computing (EC), Cloud Computing (CC), and Fifth-Generation (5G) communication technologies for creating a smart and adaptive transportation system for next-generation cities. The proposed V2X architecture enables a continuous communication among the different actors: Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), Vehicle-to-Network (V2N), and Vehicle-to-Grid (V2G). The framework not only addresses communication latency, ensures reliable packet delivery, optimizes traffic flow, but also enables proactive collision avoidance and emergency response, offering an effective solution. Moreover, the introduction of Mobile Edge Computing (MEC) technology enhances the ability to process latency-critical data closer to connected vehicles, enabling swift local decision-making without relying on a central cloud server and boosting the efficiency of safety-critical transportation systems. Moreover, AI solutions, leveraging Deep Learning and Reinforcement Learning, enable accurate traffic prediction, adaptive traffic signal optimization, intelligent route planning and autonomous decision making, allowing transportation systems to dynamically adjust to constantly changing traffic. While significant advancements have been made in connected vehicular communication, the literature survey indicated that various challenges remain that still need to be addressed in order for the V2X-enabled transportation systems to be fully and widely adopted in the real world, and these include interoperability between different types of communication technologies, cyber security risks, communication latency, privacy protection, infrastructure deployment cost, and the lack of standardized transportation data sets. The proposed framework aims to combine these technologies into a cohesive architecture that can enable scalable, reliable, and sustainable transportation management solutions, addressing the challenges and opportunities of the 4.5 transport system. The results of performance evaluation showed that the proposed AI–V2X framework outperformed conventional Intelligent Transportation Systems in terms of packet delivery ratio, communication reliability, traffic flow efficiency, congestion reduction, accident prevention, traffic signal optimization, emergency response capability, vehicle detection accuracy and overall transportation efficiency, in all major performance indicators. These developments help to improve travel time, fuel consumption, reduce greenhouse gas emissions, boost road safety and quality of urban mobility. The results indicate that the Vehicle-to-Everything communication, in conjunction with the Artificial Intelligence and edge computing, is one of the most promising technologies for the future smart transportation ecosystems. For the future, further research into integrating Sixth Generation (6G) communication, Digital Twin technology, blockchain-based security mechanisms, Federated Learning, and quantum-inspired optimization methods to improve communication reliability, cybersecurity, scalability, and autonomous decision-making is recommended. These advancements will help achieve complete and intelligent, sustainable and autonomous transportation systems that enable the development of smart cities and safe, efficient and eco-friendly mobility for the future.

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