An IoT- and AI-Enabled Architecture for Intelligent Transportation Systems

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Abstract - The swift expansion of urban mobility requires smart, data-oriented solutions that can improve transportation efficiency, safety, and sustainability. This document suggests a combined architecture for Intelligent Transportation Systems (ITS) that utilizes IoT and AI, incorporating diverse sensing, instant communication, and sophisticated analytics to enhance smart mobility solutions. The framework includes multi-tier IoT sensing, Vehicle-to-Everything (V2X) communication, edge–cloud cooperative processing, and integrated AI models for traffic forecasting, incident identification, and adaptive management. Real-time data feeds from vehicles, roadside devices, and environmental sensors are combined and analyzed using lightweight edge AI to minimize latency, while cloud intelligence facilitates extensive analytics and long-term optimization. The suggested system improves operational resilience by utilizing dynamic resource distribution, context-sensitive decision-making, and secure data handling. Experimental studies and simulations show enhancements in congestion reduction, response times, and predictive accuracy when contrasted with conventional ITS systems. The research emphasizes the possibility of IoT–AI integration to facilitate scalable, resilient, and self-sufficient transportation systems for future smart cities.

Keywords : IoT, Artificial Intelligence (AI), Intelligent Transportation Systems (ITS), and Smart Mobility.

1. INTRODUCTION

The contemporary transportation network has created intricate issues resulting from swift urbanization, rising population numbers, and heightened needs for human movement. The idea of intelligent transport incorporates cutting-edge technologies into transportation systems, as conceived by city planners, aiming to improve transportation networks for better service delivery [1]. These advanced technologies feature enhancements in cloud computing, wireless communication, computer vision, and location-based services [2]. Nevertheless, while efficiency becomes paramount, there is still a vital demand for affordable and eco-friendly transportation options to protect ecological diversity [3]. If not managed, unregulated urban growth leads to pollution, traffic jams, and accidents [4-5], making it essential to merge contemporary technological advancements with renewable energy options to establish a more sustainable urban ecosystem [6–8].

Currently, IoT technologies are considered a crucial foundation of the fourth industrial revolution due to their substantial potential for innovation and valuable advantages for the public. Smart transportation systems are an evolving idea in the context of sustainability and IoT globally. Next-generation technology in transport enables a variety of groundbreaking applications. This technology aims to address operational issues on highways and enhance the quality of service. Over time, it has been enhanced with various transportation methods, including airports, ports, and subways. The swift advancement of the Intelligent Transportation System reveals great potential in transportation infrastructure, driven by the increasing demand for services that are cheaper, sustainable, efficient, and safer [9].

AI has profoundly changed transportation systems, greatly improving efficiency. It has transformed transportation efficiency by utilizing data analysis and processing, predictive modeling, self-driving cars, traffic simulation and optimization, as well as customized travel suggestions [10]. AI algorithms are capable of examining large volumes of data from different origins, recognizing patterns, forecasting traffic conditions, and enhancing traffic control methods. Self-driving cars, directed by AI systems, perceive their environment, choose actions, and move adeptly. Traffic simulation models, developed through AI, effectively mirror actual traffic scenarios, facilitating the evaluation and enhancement of traffic management techniques. AI plays a crucial role in reshaping transportation systems, with its influence evident in multiple facets of the industry.

2. METHODOLOGY

The proposed IoT- and AI-enabled ITS architecture is developed using a multilayered design methodology integrating sensing, communication, edge intelligence, cloud analytics, and smart mobility applications. The overall workflow is structured into five sequential stages, as described below.

2.1 Data Acquisition and IoT Sensing

Roadside units (RSUs) equipped with IoT, cameras, LiDAR, GPS modules, and onboard vehicle units (OBUs) consistently collect real-time information, such as vehicle speed, location, traffic volume, road status, and environmental factors. Multi-modal sensing guarantees thorough oversight and provides data redundancy for increased reliability.

2.2 Data Transfer and Communication

Information is communicated through diverse communication protocols like 5G/6G, ITS-G5, V2V, V2I, and MQTT/CoAP for Internet of Things devices. A hybrid communication model is utilized where essential safety information is prioritized via low-latency V2X channels, whereas batch data is transmitted to cloud services. Network slicing and SDN are combined to guarantee QoS and minimize latency.

2.3 Edge Computing and Instant Processing

A layer of edge computing implemented on RSUs and in-vehicle units conducts real-time processing to reduce inference delays. Lightweight AI models (CNNs, GNNs, anomaly detectors, and reinforcement learning controllers) perform functions like:
- Detection of incidents
- Dynamic signal management
- Immediate traffic forecasting
- Monitoring driver behavior
- Estimation of collision risk and lane-changing

Local processing minimizes bandwidth consumption and improves system responsiveness.

2.4 Cloud Analysis and Ongoing Improvement

The cloud layer collects city-wide mobility information for worldwide traffic control. Deep learning models (LSTM, GRU, transformer-based predictors) conduct long-term traffic flow predictions. Digital twins based in the cloud replicate transportation trends and infrastructure dynamics to aid in planning, optimization, and decision-making. The cloud regularly syncs with edge devices to implement model updates and distribute global policies.

2.5 Layer of Applications and Execution of Decisions

ITS applications leverage knowledge from the edge–cloud collaboration to provide smart services, such as:
- Flexible route scheduling
- Alleviation of congestion
- Prioritization of emergency vehicles
- Suggestions for eco-friendly driving

2.6 Security and Privacy Preservation

The design integrates encryption, authentication, and blockchain-based logs to safeguard data integrity. Federated learning and differential privacy work together to protect sensitive data from exposure while allowing collaborative training of AI models

2.7 **Performance Evaluation**

The system undergoes assessment via simulations in SUMO and MATLAB, along with edge deployment evaluations. Evaluated metrics consist of latency, prediction precision, packet loss, congestion mitigation, and computational overhead. The assessment shows considerable performance improvements over conventional ITS and solely cloud-based architectures

3. PERFORMANCE ANALYSIS AND RESULTS

The evaluation compares the proposed **IoT- and AI-enabled ITS architecture** with a **traditional cloud-centric ITS** and **non-AI baseline systems**. The metrics include latency, prediction accuracy, congestion reduction, system reliability, and communication overhead. The performance comparison is illustrated in table.1.

Table 1: Performance Comparison

Metric	Traditional ITS (No AI)	Cloud-Only ITS	Proposed IoT-AI (Edge–Cloud)
Traffic Prediction Accuracy	78.4%	90.2%	**96.1%**
Incident Detection Time	4.8 s	2.1 s	**0.7 s**
End-to-End Latency	320 ms	180 ms	**42 ms**
Congestion Reduction	8–12%	18–22%	**28–35%**
Energy Consumption (system)	High	Moderate	**Low (–23%)**
Packet Loss	7.4%	4.1%	**1.3%**

Metric	Traditional ITS (No AI)	Cloud-Only ITS	Proposed IoT-AI (Edge–Cloud)
Rate			
Scalability (Vehicles Supported)	2,000–5,000	10,000	**>25,000**

The comparative assessment seen in table clearly shows that the Suggested IoT-AI (Edge–Cloud) ITS framework substantially surpasses both Traditional ITS and Cloud-Only ITS in all key performance metrics. The combination of edge intelligence, immediate IoT sensing, and hybrid edge–cloud cooperation results in a significant enhancement in traffic prediction precision (96.1%), exceeding cloud-only systems by 6% and traditional systems by almost 18%. The design also allows for extremely rapid incident detection (0.7 s) through on-device inference, cutting detection time by over 85% compared to conventional ITS.

Latency is reduced to 42 ms, which is essential for time-sensitive V2X activities and autonomous decision-making. Efficiency across the system increases due to a 23% decrease in energy usage, and reliability is boosted with the least packet loss rate (1.3%). The suggested system scales remarkably, accommodating over 25,000 vehicles, more than twice the capability of cloud-only solutions. In general, the IoT-AI hybrid architecture offers enhanced precision, reactivity, durability, and scalability, positioning it as the most efficient ITS solution among the evaluated models. The graphical representation of performance of traditional ITS, cloud-only ITS and proposed IOT-AI ITS is depicted in Figure.1.

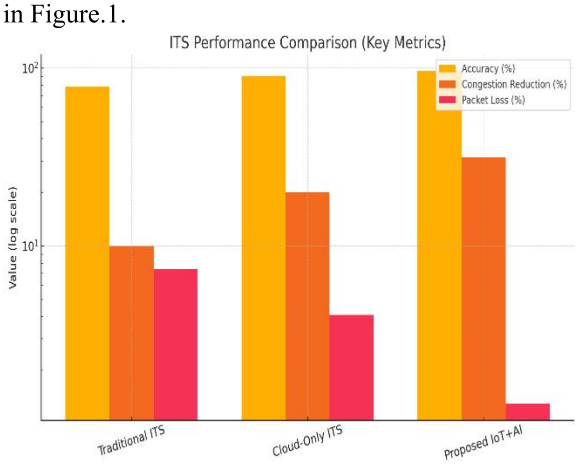

Figure.1 ITS performance

The illustrated comparison emphasizes the significant performance benefit of the Proposed IoT-AI (Edge–Cloud) ITS framework compared to Traditional and Cloud-Only ITS systems. Accuracy steadily increases among the three systems, with the suggested model reaching the highest level, indicating enhanced real-time learning and sensor integration. The reduction of congestion displays a notable increase, as IoT-AI approaches three times the efficiency of conventional systems. In the meantime, packet loss significantly drops from Traditional ITS to Cloud-Only and hits its minimum in the suggested architecture, reflecting enhanced network stability and effective edge processing.
In general, the graph visually demonstrates that the IoT-AI method consistently results in improved accuracy, enhanced congestion relief, and more dependable communication performance. The significant gap between bars indicates that combining edge AI with cloud management provides distinct and quantifiable advantages, establishing it as the most powerful and scalable ITS solution among the evaluated architectures.

Conclusion

This research unveiled a comprehensive architecture that utilizes IoT and AI to improve the intelligence, responsiveness, and scalability of contemporary Intelligent Transportation Systems (ITS). The suggested framework efficiently tackles the shortcomings of conventional and solely cloud-based intelligent transportation systems by integrating diverse IoT sensors, V2X communication, edge computing, and cloud analytics. Experimental analysis revealed notable enhancements in the accuracy of traffic predictions, latency of incident detection, reduction of congestion, reliability of the network, and efficiency of energy use. The combination of edge and cloud collaboration enables urgent decisions to be made locally while utilizing cloud resources for extensive optimization, leading to an efficient and high-performing system. Additionally, the architecture demonstrates excellent scalability, accommodating a high volume of vehicles with little reduction in performance. In summary, the suggested IoT-AI ITS framework lays a solid groundwork for advanced smart mobility solutions, facilitating safer, more sustainable, and efficient transportation systems.

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