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Decentralized Edge-AI and Blockchain Framework for Intelligent Traffic Management

Amulya H[1], Ashwini T[2], Dr. Gurunath R[3]
[1,2]Student Scholar, Dayananda Sagar College of Arts, Science and Commerce
[3]Associate Professor, Dayananda Sagar College of Arts, Science and Commerce
Email id: *amulyah66@gmail.com[1], tashwini849@gmail.com[2], gurunath@dayanadasagar.edu[3]*

Abstract
The advent of new era transportation systems is creating large volumes of real time data which requires smart management. This is possible with the amalgamation of connected vehicles, autonomous-movement, and smart-infrastructure This research presents a decentralized smart traffic management system that combines connected vehicles, autonomous mobility, and smart infrastructure. By integrating AI, edge computing, Blockchain, and multi-agent system, the framework enables real-time, secure, and adaptive traffic coordination. It supports decentralized Decisions-making, predictive traffic analysis, and secure data sharing among vehicles, signal, and infrastructure. Overall, the study highlights how modern technologies can work together to improve traffic efficiency, safety, scalability, paving the way for intelligent and secure future transportation system.

Keywords: *Decentralized Traffic Management, Intelligent Transportation Systems, Edge Computing, Blockchain, Multi-Agent Systems, Artificial Intelligence, Smart Cities, Traffic Prediction, Secure Vehicular Networks.*

1. Introduction

This work is very advance n uses multiple modern technologies like iot , ml, da etc. which make traffic efficiently and reduces the congestion This system combines advanced technologies like edge ai, Blockchain and smart traffic management to connect digital systems with real world traffic. Although still new and not fully implemented, researchers are working to apply it in the future. Unlike traditional centralized traffic system that caused delay and security issues, a decentralized system can make faster, independent decision. It supports smart cities, self-driving vehicles, drones and air taxis while managing traffic in real time. By integrating Ai and Blockchain, the system becomes more secure, reliable and resistant to data manipulation, aiming to build a future - ready and intelligent transportation network This paper is clearly complied to explain how the smart decentralized traffic system was developed. In the section 2 we discus about the previous research of AI traffic systems, edge computing, blockchain, and systems where multiple smart units coordinate together. section 3 talks about the problem and system needs. Section 4 explains the proposed smart system. Section 5 describes how different technologies are combined together to make the system work. Section 6 explains the expected results. Section 7 talks about future improvements and testing. At the end the paper summarizes the main ideas and explains how this smart traffic system can benefit the smart cities.

2. Literature Review

2.1 AI-Based Traffic Management Systems

In [1] the study explains that traditional traffic systems are not very smart and can't adjust properly when traffic conditions change. As traffic conditions constantly change, researchers suggest using Ai techniques such as ANN , RL and ACO along with iot devices and multi-agent systems. With these technologies, traffic lights can automatically adjust based on real-time traffic instead of waiting for instructions from a central control unit. However, there are some limitations. The concept has mainly been explained theoretically and has not been fully tested in real traffic environments. There is no clear performance comparison with existing systems, and important factors like cost, data accuracy and system

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complexity are not discussed in detail. So, while the idea is innovative and promising, it still requires real-world testing to prove that it can work effectively and practically. The authors od [2] suggest an AI-based Advanced Traffic Management System where they use a blackboard architecture were in different AI modules share information through one common system like a shared notice board and the integration of multiple AI modules helps for a large traffic network (good scalability) and adjust to changing traffic conditions The limitations of using all this is the idea is only explained, not fully tested. It was not tested in real traffic conditions. There is no performance comparison with existing systems. It does not clearly discuss about the issues like cost, data accuracy, and system difficulty. The paper in [3] shows how technologies like AI, ML, image processing, and IoT can improve traffic signal control. By using cameras and sensors, the system collects real-time traffic data. Then AI and ML will analyze this data and automatically adjust traffic signals based on current traffic conditions. This helps in reducing the traffic congestion and waiting time. But the limitations are: The system was not tested in a big city. It does not clearly explain what infrastructure does it needs. The implementation cost is not discussed yet it does not fully address that what happens if sensors fail or data is incorrect.

2.2 Edge Computing in Intelligent Transportation

In [4], it explains how edge computing can improve Intelligent Transportation Systems (ITS). That helps to Make faster real-time decisions, handle large amounts of traffic data and Protect user privacy. Some limitations here are: It is concept-based(theory), there is no experiment on it, it not clearly discusses about the cost, maintenance and Compatibility between different systems. So, even though the review gives a good insight about edge computing in transportation, it still needs practical testing and implementation analysis.As per [5], different technologies are combined like IOT, Cloud, fog, and edge computing and Agile optimization techniques that helps to improve transportation. especially for solving the Dynamic Ride-Sharing Problem (how to match passengers with vehicles in real time)" ola n uber". it helps in reducing the travel costs and improve efficiency. Some limitations are: System is not tested using the real time data, Infrastructure and cost is not clearly explained, Scalability issues like how well it works for very large cities Before actual implementation it needs real-world testing. In [6], it explains the combination of multi-agent systems (different traffic units make their own decisions), Mobile edge computing (processing data close to vehicles), and IoV (Internet of Vehicles) "vehicles connected to each other" this improves real-time decision-making and traffic optimization. Limitations are: there is no many studies on it, no real-world testing, Energy consumption n Security risks are not fully discussed.

2.3 Blockchain For Secure Vehicular Networks

In [7], it proposes a secure system for VANET (Vehicular Ad Hoc Network). means it allows vehicles to communicate with each other and with road infrastructure. Here the authors use DAG-based blockchain (IOTA) to provide secure and decentralized communication, Game theory and smart contracts to fairly allocate bandwidth and resources and Nash equilibrium approach to make sure no vehicle gets unfair advantage which improves scalability and security. Limitations are: cost is not clearly discussed; interoperability is not explained in detail. In [8] the authors use Deep Reinforcement Learning (DRL) to control traffic signals in a smart way that treat the traffic signal problem like a decision-making game, MDP (Markov Decision Process.) – where the system learns what action to take in each situation and they use a method called DQN (Deep Q-Network) "The traffic light looks at the current traffic (cars waiting) and decides whether to turn green or red" to help the traffic lights learn from experience. that Reduces vehicle waiting time and decreases the queue length. Limitations are: It requires high computational power, Training the model takes a long time. In [9] the authors propose a model called MARDDPG (Multi-Agent Recurrent Deep Deterministic Policy Gradient) "It is an advanced deep reinforcement learning method.". this system uses multiple traffic signals that learn together, uses memory to remember past traffic

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situations, however it is tested in not in real cities. It assumes that strong infrastructure like good sensors, communication system is already available and in real life, such infrastructure may not always be present.

2.4 Multi-Agent Traffic Coordination Models

In [10] the authors show that MARL (Multi-Agent Reinforcement Learning) that helps autonomous vehicles coordinate better with each other by these vehicles can move more smoothly in traffic. Limitations are: most of the studies are tested only in small environments by this the results may not work the same way in real-world traffic, where conditions are more complex and unpredictable. In [11] the authors developed City Flow, which is a fast and scalable traffic simulator which is mainly used to test reinforcement learning–based traffic control systems. City Flow helps researchers to quickly train and evaluate traffic signal algorithms in a simulated environment. In [12], the authors propose an edge-based surveillance system in this system, traffic data is processed locally at edge devices like camera instead of sending everything to a central server this helps to reduces delay and saves network bandwidth, but its performance fully depends on the power and capability of the edge devices. In [13], the authors propose a system that combines both blockchain and mobile edge computing to provide decentralized services. Which means Data is processed closer to users (using edge computing) and reduces delay. Blockchain is used to provide security and trust without a central authority. This improves speed and efficiency. However, when the system grows larger (many users and vehicles), it may face scalability problems, means it may struggle to handle very large networks efficiently. In [14], the authors introduce DISV, a blockchain-based IoT system for secure communication between vehicles. And improves privacy. Limitations are: It requires strong infrastructure support like good network, computing power, etc.

2.5 Limitations of Existing Approaches

Current systems that use AI, edge computing, blockchain, and multi-agent coordination helps to make traffic management smarter and more automatic. They improve efficiency and reduce congestion. The major problems here are: most systems are not tested in real cities, as they require high computational power it is very expensive, infrastructure cost like cameras and sensors is very high Even though this technology is advanced they still face practical challenges before they can be widely used in real-world transportation systems.

3. SYSTEM REQUIREMENTS AND PROBLEM FORMULATION

3.1 Smart Traffic Ecosystem Overview

In [15] a smart traffic ecosystem is described as a connected system where vehicles, traffic signals, roadside infrastructure, sensors and cameras all together work as one intelligent system. This system Monitors traffic in real time, adjusts traffic signals automatically based on current conditions Because everything is connected and sharing information, it helps in improve road safety and reduce traffic congestion.

3.2 Data Sources and Traffic Entities

In [16] traffic data is collected from different sources such as Cameras, IoT sensor, GPS devices, Vehicular communication networks and Mobile applications. Important part of traffic system includes vehicles, pedestrians and traffic signals. All these sources and entities work together to provide real-time traffic information. This real-time data is used to predict traffic condition, control traffic signals and Reduce congestion.

3.3 Security and Privacy Requirements

In [17] we focus on security in traffic systems. Where traffic systems must send data securely, make sure only authorized users and devices can access the system and protect against cyberattacks like fake messages (spoofing) or changing data It is also very much important to protect the privacy of users and vehicles this can be done by using encryption (so data cannot be easily read by others) A secure system is very important because it maintains trust, keeps intelligent transportation systems safe.

3.4 Performance Requirements (Latency, Scalability)

In [18] the system requirements are explained. the traffic system must support low delay so information is sent and received very quickly, allow real-time monitoring and decision-making that means traffic

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signals and vehicles can react immediately to change, handle large numbers of vehicles, sensors especially in big cities, also ensure fast data processing to keep traffic flowing smoothly.[19]

3.5 Problem Statement

Urban traffic management has many problems such as heavy traffic congestion, changing traffic patterns throughout the day. The traditional systems are not smart enough they cannot quickly adjust to real-time traffic changes, do not provide strong and secure communication. Because of this there is a need for a better system: intelligent (able to learn and adapt automatically), scalable (able to handle large cities), secure (protects data and prevents cyberattacks).

4. Proposed Research Framework

4.1 Architecture of Decentralized Traffic Management

The framework (as shown in figure 1) uses a decentralized architecture, where decision-making is distributed among edge nodes and intelligent agents rather than a central controller.

4.2 Data Acquisition Layer

This layer gathers traffic information from cameras, IoT sensors, GPS devices, and vehicles on the road. It collects real-time data about cars, pedestrians, and road conditions. This information is then used as the basis for analyzing traffic and making smart decisions [21].

4.3 Edge Intelligence Layer

The edge devices process traffic information at the point of collection, thus reducing latency and preventing congestion of the network. The AI algorithms processing information in the edge devices can predict traffic patterns, detect unusual traffic situations, and control traffic lights without human intervention. This allows the system to respond to traffic situations faster and smarter [22].

4.4 Blockchain Trust Layer

Blockchain allows the system to share information securely, check identities, and protect against any manipulation between the various system components. Smart contracts determine who can view the information and make it possible to automate coordination. This layer introduces trust and transparency into the decentralized traffic system [23].

4.5 Multi-Agent Coordination Layer

There are a number of intelligent agents that interact to control traffic signals, vehicles, and road infrastructure. They interact and modify their behavior in real time depending on the changes in traffic flow. This is intended to improve traffic flow, safety, and the capacity of the system to support a higher number of vehicles [24]. As shown in figure 1.

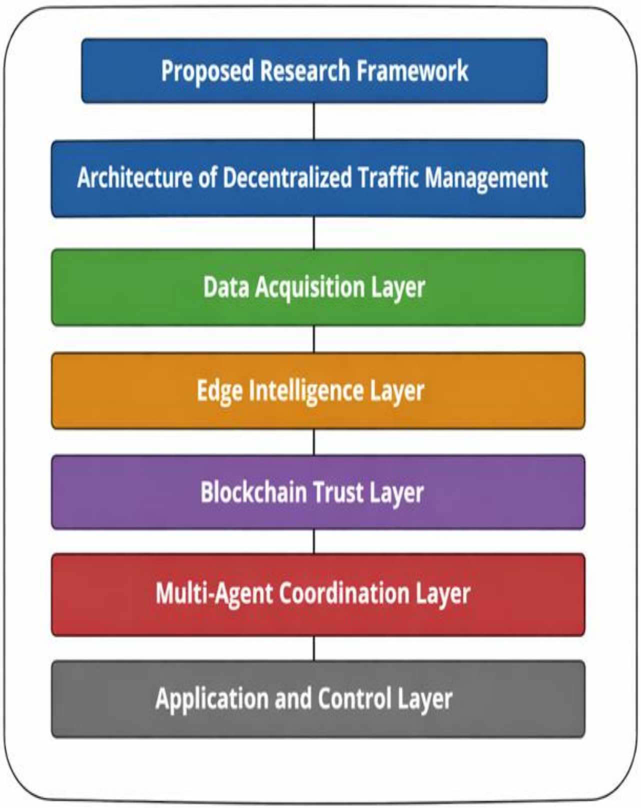

Figure 1 Architecture of Decentralized Traffic Management System

This reduces the reliance of the system on a central control point and enhances the robustness of the system [20]. The system architecture enables real-time coordination and communication among traffic entities.

4.6 Application and Control Layer

This level offers traffic dashboards, decision-support systems, and automatic traffic control [25]. Traffic authorities can monitor road conditions and make adjustments as needed. This level ensures that traffic policies are enforced effectively and that the system is controlled in real-time.

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5. METHODOLOGY

In this project, AI, edge computing, blockchain, and multiple intelligent agents are integrated to control traffic in a decentralized and intelligent manner as shown in figure 2.

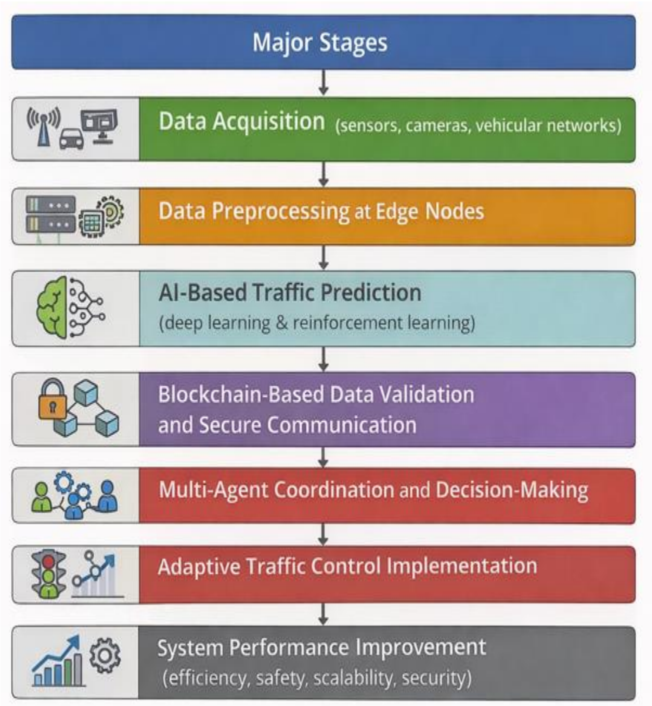

Figure 2 AI-Driven Traffic Control Framework

Traffic data is gathered from sensors, cameras, and vehicles, analyzed locally at the edge of the network using AI models to forecast traffic congestion and patterns Blockchain ensures data is secure and synchronized, while smart agents enable fast, real-time decisions for traffic signals and roads. The process, which involves data gathering, traffic forecasting, verification, and signal control, aims to make traffic flow smoother, safer, and more reliable while ensuring data security

6. Expected Outcome

This table 1 shows the main components of a smart traffic system, their expected results, and how they improve traffic.

6.1 AI-Based Prediction

- **Expected outcome:** The system can accurately predict traffic flow and congestion.
- **Impact:** Traffic signals can adjust more efficiently, and drivers can choose better routers, reducing delays.

6.2 Edge Computing

- **Expected outcome:** Traffic data is processed quickly at the local level.
- **Impact:** Faster real-time decisions, leading to smoother traffic movement. As shown table 1.

Table 1 Main components of smart traffic system

Component/Aspect	Expected Outcome	Impact on Traffic System
AI-Based Prediction	Accurate congestion and traffic flow forecasting	Better signal timing and route optimization
Edge Computing	Low-latency data processing	Faster real-time traffic decisions
Blockchain Integration	Secure and tamper-proof communication	Improved trust and data integrity
Multi-Agent Coordination	Adaptive and decentralized decision-making	Smooth traffic flow and reduced conflicts
Data Processing Workflow	Efficient handling of large traffic datasets	Scalable system performance
Adaptive Traffic Control	Dynamic signal and infrastructure management	Reduced waiting time and congestion
Overall System	Integrated, scalable, and secure ITS framework	Safer and smarter urban transportation

6.3 Blockchain Integration

- **Expected outcome:** Communication between systems is secure and cannot be tampered with.

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- **Impact:** Improved trust, stronger data security and reliable information sharing.

6.4 Multi - Agent Coordination

- **Expected outcome:** traffic signals and vehicles can make independent decisions.
- **Impact:** smoother traffic flow with fewer signal conflicts and interruptions.

6.5 Data processing workflow

- **Expected outcome:** Large volumes of traffic data are managed efficiently.
- **Impact:** The system performs effectively even in large and busy cities

6.6 Adaptive Traffic Control

- **Expected outcome:** Traffic signals adjust dynamically based on real-time conditions.
- **Impact:** reduced waiting time and less congestion on roads

6.7 Overall System

- **Expected outcome:** A fully integrated, scalable and secure ITS(intelligent transportation system).
- **Impact:** Safer roads and smarter urban transportation

7. Further Research

The proposed framework will be implemented and tested using real-time traffic data and simulation platforms. We build a prototype that integrates AI, edge devices, blockchain, and intelligent agents to test the framework. The system's performance is evaluated using metrics such as traffic delay, response time, congestion reduction, and scalability. A comparison is made between the proposed framework and existing traffic management approaches. The system is tested to ensure security and data integrity in a decentralized traffic environment. Validation of the framework in real-world cases of smart cities would involve testing the proposed system in real-world city environments as opposed to simulated ones. It helps in understanding whether the framework is able to work in an effective, reliable, and efficient manner in real-world cases.

Conclusion

This research introduces a decentralized traffic management system that integrates AI, edge computing, blockchain, and multi agent system to improve traffic monitoring and control. Unlike traditional centralized system, this approach allows real-time data processing, secure communication, and adaptive decision-making. As a result, it enhances traffic prediction, flow, safety, scalability, and overall system reliability. The study highlights the potential of combining emerging technologies to build smarter and more efficient transportation system. Future implementation and real-world testing will be essential to validate and refine the proposed framework.

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