Challenges and Solutions of IoT-Enabled Traffic Surveillance Systems: A Comprehensive Survey

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Abstract: The demand for effective traffic management solutions has increased due to the fast urbanization and rising vehicle density. IoT-enabled traffic surveillance systems have become a viable way to improve road safety, traffic monitoring, and congestion management. Data security, real-time processing constraints, interoperability problems, and high deployment costs are just a few of the major obstacles these systems must overcome. This survey examines various remedies and offers a thorough examination of these issues. We look at important approaches including 5G-enabled communication frameworks, edge computing, blockchain for safe data sharing, and analytics powered by artificial intelligence. We also evaluate new developments and industry best practices that improve the dependability and effectiveness of IoT-based traffic monitoring. Our results emphasize how crucial it is to combine secure communication protocols with sophisticated data processing methods in order to overcome current constraints. The purpose of this study is to help policymakers and researchers create IoT-driven traffic control solutions that are more reliable and scalable.

Keywords: Internet-of-Things, Cloud computing, Fog computing, Smart traffic monitoring

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I. INTRODUCTION

The Internet of Things (IoT) consists of items with distinctive features and connectivity to the Internet. The "things" in the IoT are IoT devices having unique identities and the capacity for remote sensing, actuation, and monitoring. Today, the Internet has almost reached every country in the globe, and its influence on how people live their lives is unimaginable. Applications for IoT extend beyond simply connecting objects to the Internet. IoT makes it possible for these devices to share information while executing essential applications for a typical user's or machine's goals. By enabling sophisticated and networked monitoring systems, the Internet of Things (IoT) has completely changed traffic surveillance. IoT-enabled traffic surveillance systems gather, process, and analyze traffic data in real time using a network of sensors, cameras, and cloud computing. Notwithstanding their benefits, these systems have a number of drawbacks, such as high implementation costs, network latency, data security, and compatibility.

Fig 1. IoT Eco System [IoT&ApplicationsDigitalNotes.pdf(mrcet.com)]

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At the moment, cloud servers handle and store the majority of IoT data. The cloud provides a highly scalable computing infrastructure that can be configured on-demand in a pay-as-you-go fashion. Cut down on the cost of creating the required analytics application. The current data analysis methodology can handle processing huge data volumes kept in centralized cloud storage [7]. The cloud is used to store data. Edge computing, often known as fog computing, is a novel strategy that has been developed in response to the complexities and dynamic nature of the Internet of Things (IoT) [8].

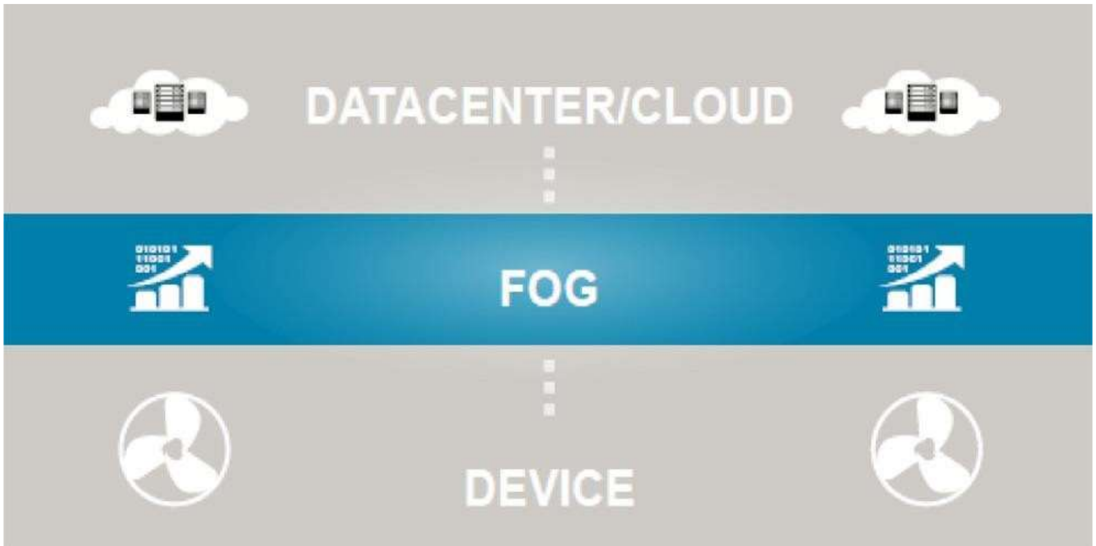

Fig 2. The Network Edge[1]

Previous research has mostly concentrated on particular areas, including data analytics, security risks, or vehicle communication. For instance, prior surveys have looked at the function of edge computing and wireless sensor networks (WSNs) in traffic monitoring, but they frequently don't provide a comprehensive analysis of the various issues these systems confront. Furthermore, although some research has tackled cybersecurity issues in IoT-driven surveillance, it hasn't thoroughly examined solutions designed for various traffic monitoring settings.

This survey article discusses how to build intelligent traffic monitoring systems that accommodate cloud computing and fog computing while addressing the limitations of traditional cloud services for traffic monitoring systems. A vehicle detection sensor is connected to the fog node in this system. Data can be processed locally by fog nodes before being sent to the cloud for further examination. Additionally, comparison studies are conducted to highlight the benefits of fog networks over cloud computing in terms of response time and bandwidth. The development of different techniques depends on the building of automated systems. This study will discuss several traffic monitoring techniques, such as fog computing design for vehicle data classification, cloud computing design for vehicle data classification, traffic signal control, and congestion detection. The rest of this paper is structured as follows: Section II explores different traffic monitoring techniques utilized for vehicle classification. Section III presents a literature review on intelligent traffic monitoring approaches. Finally, Section IV provides the conclusion of the paper.

I. TRAFFIC MONITORING METHODS

Here we will discuss few important methods of traffic monitoring and vehicle classification.

A. Vehicle data classification with cloud computing [1]

A Vehicle in terms of data, traffic data analysis in the cloud to identify vehicle congestion in traffic then Installing sensors on roads to detect traffic at a designated intersection and upload in grew data to the cloud to determine how many vehicles will approach the junction in a specific amount of time. Analyzing the processed data to classify vehicle congestion levels as LOW, MEDIUM, or HIGH, depending on the number of vehicles at the intersection. Depending on a pre-determined threshold, classifying the congestion density as LOW, MED or HIGH. In the event of HIGH congestion, the cloud platform will send a Tweet message (#Traffic Density HIGH-CLOUD) as an alert.

Predicting occurrences like car accidents, breakdowns, road repairs, etc. if the congestion is classified as HIGH.

B. *Fog Computing Design for Classifying Vehicle Data[1]*

As a component of this process vehicle and traffic data from the cloud Identify the output of data analysis—car congestion in the road firstly, follow the procedure Installing sensors on roadways to monitor traffic at a chosen crossroads, then uploading unprocessed data to the cloud to estimate the number of cars that will approach the in trisection in a given period of time and classifying vehicle congestion as LOW, MED, or HIGH based on the number of cars at the intersection using the processed data after analysis. employing a predetermined threshold to designate the designations for the congestion density HIGH, MEDIUM, or LOW. The cloud platform will tweet an alert with the hash tag #Traffic Density HIGH-Cloud if HIGH congestion is detected. A neighboring fog node (#TrafficDensityHIGH-Fog) receives the raw data and counts the number of vehicles before processing it. Predicting events like car accidents, crashes, and road If the classification of the congestion is HIGH, repairs, etc.

C. *Congestion detection[1]*

As a Input in this method Traffic data from sensor Initially Check the vehicle Density and vehicle Density is Low then Increment vehicle Count for every incoming vehicle. If vehicle Count is High vehicle Density is #Traffic Density HIGH)High Tweet(Traffic Density HIGH) Display. As a result of traffic data from sensor nodes, we were able to detect congestion.

D. *Traffic light control[1]*

As a Input in this system Traffic Signals information system. In initial stage check traffic signal, then traffic signal light is red so Vehicle Density is high and same as traffic signal light is green so Vehicle Density is low and we got as a Output is the vehicle concession as a basis for traffic light.

II. LITERATURE SURVEY

The research summary and future scope of this study will be presented in the current section along with various research papers pertaining to smart traffic monitoring and vehicle classification using cloud and fog computing.

Investigating how the fog computing technique might improve the performance of conventional technology for cloud computing is the aim of the current study, which is based on [1] works for traffic monitoring systems. to demonstrate how a fog-based system outperforms conventional cloud-based technologies in terms of bandwidth and response time for applications that are sensitive to latency. Preliminary experiments are conducted. A traffic monitoring system is looked at as a case study. It is found that the response time and bandwidth of the fog network are around 258 times faster than those of the cloud network, while the bandwidth of the cloud network is almost 5 times smaller.

In paper [2] researchers developed To traffic control performance Adaptive traffic system include multiple technologies such as loop detector, camera detector, infrared, radar, etc. To further improve traffic control performance, adaptive traffic system includes loop detector, camera detection includes multiple technologies such as vessels, infrared, radar, etc.

The drone serves as an empty camera sensor to monitor the area of interest in our experimental surveillance system described in paper [3]. The ground controller receives the raw video stream, which is then shown on the security screen. When an application user spots a suspicious vehicle, the target is blocked and a video frame is sent to the fog node for tracking and speed calculation, according to a case study on intelligent traffic monitoring. The results and processed patches are promptly transmitted back to the ground control station after the speed has been determined. taking into account the HD video frame's dimensions.

In the article [4] Data collection, cleaning, clustering, time series comparison, data retrieval for visualization, chart and report creation, and mobile client notifications are among the system's capabilities. The system employs a special agent for remote photo and video fixation in order to gather statistics and aid in decision-making. complicated and automated data upload. The agent gathers and downloads various sensor data pertaining to traffic parameters, as well as images and frames from the video stream.

The article [5] describes a fog machine in which the number of images sent represents the total amount of time spent monitoring. Since the video was made with a frame size of 20 frames per second, I assumed that there was a violation every five minutes (the worst case scenario). After 100 minutes of monitoring with 20 moving violations, the camera records a total of 120,000 frames of the vehicle in front.

In the article [6] Many of the features of cloud computing, from which fog computing is derived, are retained. Users can still keep their packages and data offsite, and they can now pay for more than just offsite storage—they can also get cloud enhancements and protection for their data, including the use of fog computing mode.

In the destiny work [7], we are able to layout simulations on actual town maps and acquire greater actual site visitors information to provide a automobile generation model (taking rush hour into consideration). Also, we are able to uppload well-informed smart vehicles (dynamically making plans its course from street information) with the aid of using smart simulators and algorithms to perceive the benefits of our framework

TABLE I:
OVERALL SUMMARY OF LITERATURE SURVEY

Sr. No.	Paper Title	Author contribution	Result	Future Scope
1.	Internet of Things-based Fog and Cloud Computing Technology for Smart Traffic Monitoring [1].	A cloud and fog computing architecture is proposed to improve complicated surveillance systems in terms of reaction network capacity and time.	As an example, let's look at a traffic monitoring system. Even though the fog network's reaction time and bandwidth are 258 times quicker, the cloud's bandwidth is just roughly a sixth of the fog's.	Create a car generation model, we will create simulations using real city maps and more real traffic data in the future (taking into account the attacker). To determine the benefits of our framework, we will also be well-informed about intelligent vehicles (dynamic route planning based on road information).
2.	Phase Timing Optimization for Smart Traffic Control Based on Fog Computing.[2].	Proposing a fog- based intelligent traffic signal system Traffic data is stored in a control architecture. Mostly from Edges rather than the middle of distant clouds, collected by different sensors..	In order to further enhance traffic management effectiveness, adaptive transportation systems use a variety of technologies, including B. Loop detector, cameras, infrared, and radar	In future work, we plan to design and implement software units that can support adaptable updates and upgrades to adapt to new control policies.
4.	Intelligent monitoring system for smart road environment [4]	Photo-video fixed remote inquiries Complex and automated data uploads are handled by a dedicated agent in the system Photos and frames from the video stream, and also sensor data pertaining to traffic factors.	Network results showed acceptable errors with an averageof13% prediction. These variations in the number of incidents and their influence on temperature regimes might be predicted using this model.	In future we have to try to implement web cam on road so this device give advance information about road traffic.

5.	Smart traffic control: Identifying driving-violations using fog devices with vehicular cameras in smart cities [5]	Each time the machine is activated, a certain number of photos are communicated. He assumed that the video has been created at a framerateof20fpsandthat a violation occurred every five minutes.	Given the size and length of the video, the system efficiency statistics show a good Throughput and a fast processing time	At the beginning, a lane detection algorithm employing the Hough transform and a vehicle detection mechanism utilizing SSD
6.	Smart Fog Based Workflow for Traffic Control Networks [6]	A traffic management system based on fog-based intelligence Because of the computational paradigm and the dispersion gain method.	Optimization is the key. A network of interconnected automobiles and strategies for their reinforcement Leading developer of next-generation smart transportation technologies.	Design the simulation the more real traffic data on a real city map to create a generation vehicle

TABLE II:

COMPARISON TABLE SUMMARIZING KEY APPROACHES FOR IOT-ENABLED TRAFFIC SURVEILLANCE SYSTEMS:

Approach	**Accuracy**	**Scalability**	**Cost**	**Response Time**	**Real-World Applicability**
Computer Vision-Based	High	Moderate	High	Fast	Widely Used
AI/ML-Based Analytics	Very High	High	High	Fast	Emerging
Sensor-Based (e.g., RFID, LIDAR)	Moderate	High	High	Moderate	Industry Adoption
Crowdsourced Data (e.g., GPS, Mobile Apps)	Moderate	Very High	Low	Fast	Popular
Hybrid (AI + Sensors + Cloud)	Very High	Very High	High	Fast	Future Trend

IV. OPEN RESEARCH CHALLENGES

IoT-enabled traffic surveillance systems have advanced, however there are still a number of unresolved research issues. The enormous volume of data produced by sensors, cameras, and connected cars necessitates effective processing, storage, and real-time analysis, making data management and scalability a major challenge. Because IoT devices are vulnerable to cyber attacks, unauthorized access, and data breaches, ensuring data privacy and security is also a crucial concern. Furthermore, as different IoT devices, communication protocols, and platforms must work together seamlessly to provide efficient surveillance, interoperability and standardization present challenges. In order to ensure accurate vehicle and pedestrian detection, traffic monitoring systems must handle a variety of environmental conditions, such as poor lighting, occlusions, and changing weather conditions. Additionally, the cost and upkeep of IoT infrastructure can be a barrier to widespread deployment, especially in developing regions. Finally, ethical and legal concerns regarding surveillance, data ownership, and citizen privacy must be addressed in order to promote public trust and regulatory compliance. The deployment of edge and cloud computing for real-time decision-making also requires further optimization to balance latency, energy consumption, and computational efficiency. Finally, enhancing the resilience of IoT-based traffic systems against failures, cyberattacks, and harsh weather remains a crucial research focus. Addressing these difficulties will enable the creation of more robust, efficient, and secure IoT-enabled traffic surveillance systems for smart cities.

Here’s a critical analysis of the surveyed works on IoT-enabled traffic surveillance systems:

Strengths of Existing Approaches

1. **Enhanced Accuracy through AI & ML**
   - Advanced deep learning techniques improve object detection, classification, and anomaly detection in traffic monitoring.
   - Real-time decision-making is possible with edge computing integration.
2. **Scalability and Data Collection**
   - IoT devices (sensors, cameras, and GPS) enable large-scale data collection.
   - Cloud-based architectures support real-time analytics on massive datasets.
3. **Automation and Predictive Analytics**
   - AI-driven predictive analytics help in congestion prediction, accident prevention, and optimized traffic signal control.
   - Automation reduces human intervention, increasing system efficiency.

Gaps and Limitations

1. **Data Privacy and Security Concerns**
   - IoT devices are vulnerable to cyberattacks, leading to potential data breaches.
   - Ensuring secure data transmission and storage remains a major challenge.
2. **High Deployment and Maintenance Costs**
   - Implementing high-resolution cameras, LIDAR, and AI-driven systems is expensive.
   - Maintenance and system integration costs limit adoption in developing regions.
3. **Limited Real-World Validation**
   - Many studies rely on simulations rather than real-world implementations.
   - Scalability challenges emerge when tested in uncontrolled environments.
4. **Latency and Response Time Issues**
   - Processing large volumes of real-time traffic data can lead to delays.
   - Edge computing solutions help but require significant infrastructure investment.
5. **Heterogeneous Data Sources and Standardization Issues**
   - Integrating data from different IoT devices, mobile apps, and traditional surveillance systems lacks standard protocols.
   - Data fusion techniques are needed to handle multi-source inconsistencies.

V. CONCLUSION

Through the use of cutting-edge technology like artificial intelligence (AI), computer vision, sensors, and cloud computing, IoT-enabled traffic surveillance systems have greatly enhanced traffic management. There are still a number of obstacles to overcome despite their benefits in increasing traffic monitoring, lowering congestion, and boosting road safety. These include the requirement for real-time processing, network scalability, significant implementation costs, and data privacy issues. To lessen these difficulties, a number of alternatives have been put forth, including edge computing, blockchain for security, and hybrid AI models. A comparative study of various methods reveals the compromises between scalability, cost, accuracy, and practicality. All things considered, IoT-driven traffic surveillance is still developing and promises to provide more intelligent and effective urban mobility solutions.

VI. FUTURE SCOPE

The integration of cutting-edge technologies to solve current issues and improve efficiency is key to the future of IoT-enabled traffic surveillance systems. Optimizing edge computing to allow for real-time traffic monitoring with lower latency and less dependence on cloud infrastructure is a crucial field of research. Furthermore, maintaining data security and privacy is still a major challenge, requiring the creation of strong encryption methods, blockchain-based authentication, and AI models that protect privacy like federated learning. High-speed data transmission is made possible by the quick development of 5G and next-generation networks, which enhances the scalability and reactivity of IoT-based surveillance.

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