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ENCRYPTION-BASED SECURE FRAMEWORK FOR SMART TRAFFIC MANAGEMENT USING FOG COMPUTING

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ABSTRACT

Inevitable traffic congestion has resulted from a growing population and their associated automobile requirements. In addition to diminishing the quality of everyday living, traffic congestion has long-term negative effects on an economy. Smart cities must be based on intelligent management systems, with traffic management at their centre. Smart traffic management (STM) depends on acquiring real-time data, processing, and organising the flow of traffic. This data can be acquired from different sources, including cameras, magnetic or piezo sensors, radar, and roadside units (RSU). Data collected from these various methods can be used to manage the traffic systems. However, the processing of data is central to smart traffic management. This analysis presents the application of fog computing to process the traffic data collected from different devices. The Fog computing architecture allows us to improve the latency, which enhances the overall performance of the system. Fog computing also reduces network usage compared to cloud computing. Here, a framework is presented, composed of various cameras and sensors that collect the data and transfer it to the fog nodes where it is processed and returned to the display. This would also assist in managing the traffic lights depending on the estimated congestion time.

Keywords: *Fog Computing, Smart Traffic Management, Fog Node, Edge Node, Cloud Node, Fog Computing Architecture*

1. INTRODUCTION

Many developing countries are coming up with a plan for smart cities where technology would play a key role in organizing each sector. However, growing populations and migration still pose a serious challenge for traffic management [1]. Large number of vehicles on the road are sign of a growing economy, cost of vehicles is declining due to high competition in the market. These conditions also increase traffic congestion [2]. There is a huge capital loss reported due to traffic congestion, which includes fuel wastage. Traffic congestion also affected freight vehicles and increased the waiting time on highways. Reducing the time and frequency of traffic congestion depends on the application of real time data efficiently and informing the driver. Big data modelling has the potential to address the traffic congestion concern [3,4]. The examination of large data sets offers an effective method for predicting outcomes. In traffic management, the data is collected in real time, employing a multitude of approaches. In addition, maintaining real-time data presents the challenge of latency. In this context, data transmission is often a time-consuming activity that limits the deployment of real-time big data analysis and forecasting. Moreover, the challenges of providing reliable data storage and retrieval services through cloud computing are highlighted, with fog computing introduced as a potential solution. However, the implementation of fog computing brings up security concerns, specifically related to privacy and access control. Various privacy preserving and access control schemes in fog computing are compared, and suggestions are presented for enhancing security algorithms. This information is intended to educate researchers and practitioners about the need to address privacy and access control issues in fog computing for secure data storage and retrieval[5].

Implementation of fog nodes in traffic data management might reduce network utilisation and minimize latency. The fog computing architecture provides data processing and storage between the data source and the cloud. As this design offers a

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cloud-ahead platform, data transmission is accelerated. However, fog computing is not seen as a substitute for cloud computing, although it is very effective for short-term data analytics. Frequently, data processed at fog nodes is transferred to cloud nodes for long-term storage. These IoT sources are termed as edge devices that includes camera, sensor etc. Figure 1 shows the setup of fog computing.

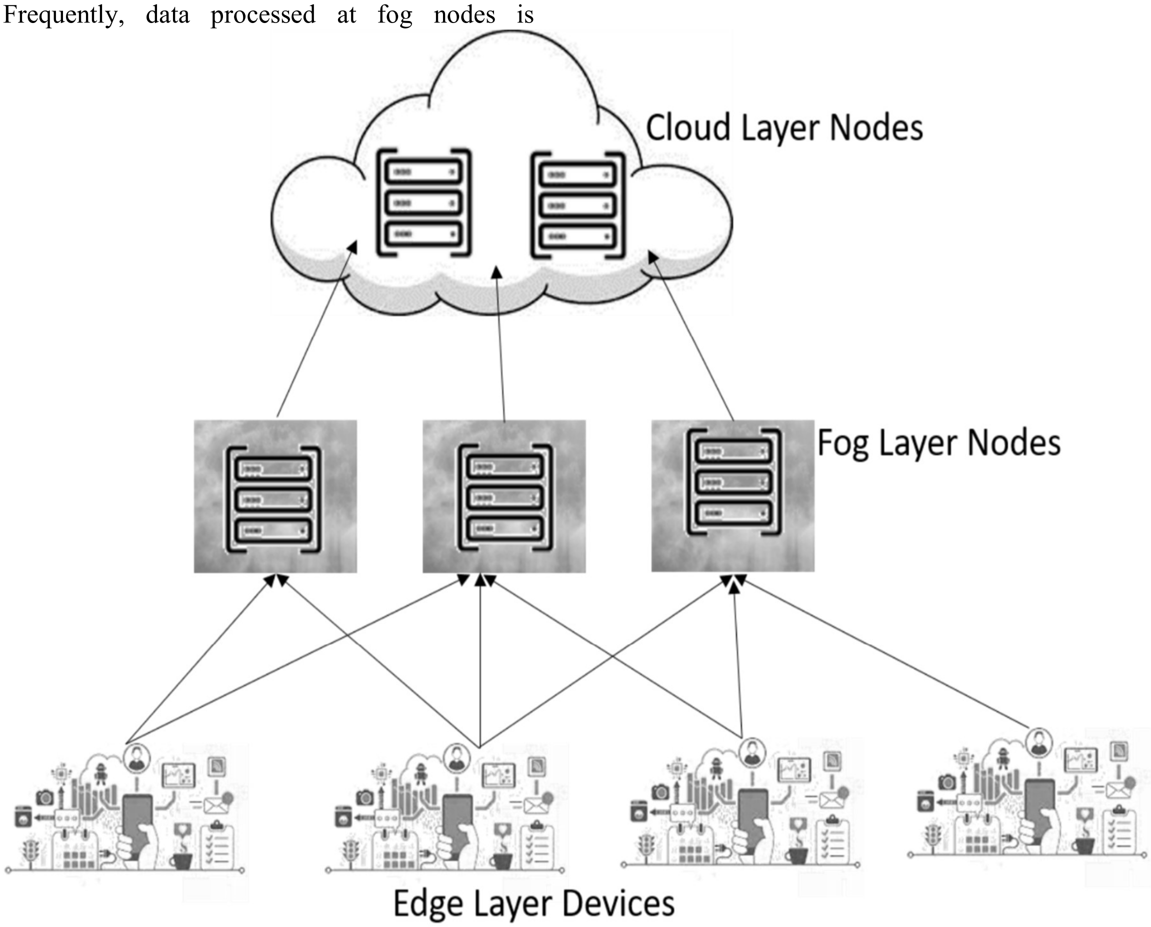

Figure 1. Working Principle Of Fog Nodes, Data Transferred From The Edge Layers, Processed On Fog Nodes, And Transferred To Cloud Layer Nodes.

2. BACKGROUND

A smart traffic management system depends on the installation of different devices and the collection of data. The process of data collection in the IoT is challenging [6]. Each device has a set of limitations in data acquisition and loss of data or missing information is associated with it. However, advanced technologies can find the missing information and more robust data collection techniques [7–9]. Cameras and sensors are the two most commonly used devices for collecting real-time data. A camera is used to detect the vehicles by capturing the image of their number plates [10]. In many countries where lane driving is strictly followed, que detector sensors could be buried to determine the traffic congestion. Cambridge City used this technique, but as the system was centralized, that caused network usage that resulted in latency [11]. Video cameras are a superior option to image-capturing cameras. However, data in video cameras needs to be compressed before being transferred over the network [12]. Moreover, the quality of the data is affected by climate conditions.

Infrared sensors are used to detect the energy emitted by the vehicles, which is used for traffic information transfer [13]. However, this is also affected by climate conditions. Real-time traffic management systems are used by traffic agencies to dynamically control recurring and non-recurring congestion in real-time [14]. In various

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studies, microcontrollers are used to control traffic and are proven as intelligent systems [15]. The PLC based systems were also reported to manage the traffic [16]

Recently, machine learning methods have been applied to traffic management. Kashi et. al. presented a framework that used wavelength transformation and artificial neural networks (ANN) to predict the short term traffic flow [17]. In this framework, the flow of the traffic for the next 30–35 minutes is predicted and shown to the driver, as sometimes real-time information takes time to reach the driver. Similar traffic flow predictions were also performed using support vector regression (SVR) [18]. Clark showed a method of multivariate non-parametric regression to predict the flow of traffic [19]. Deep learning methods were also employed in traffic flow prediction to manage traffic [20].

All the advanced technologies use the data and process it to produce a decision control system. Processing of data needs compute power, and very often it is performed on the cloud. C. Lyons submitted a thesis on the feasibility of using cloud computing for urban traffic management. Other studies also showed the role and importance of cloud computing in traffic management systems where IoT worked as the core of the system [21,22]. However, the cloud interface increases the time of processing as the data must be transferred from edge nodes to cloud nodes. The current solution to the problem of latency is the implementation of fog nodes that are placed between the edge nodes and cloud nodes. Fog computing offers multiple services that include a shorter service response time, localized computing capability, lower data transmission load, a safer decentralized service architecture, and faster and more accurate analysis with decision-making and control. Fog computing was applied to propose a scheme for secure traffic light control using the Diffie–Hellman puzzle and the hash collision puzzle methods [23]. The Wireless Sensor Network (WSN) is based on fog computing, which reduces data exchange events and thus improves performance. [24]. This study analysed the traffic congestion using fog computing.

3. RELATED WORK

Recently, a model driven approach was presented by Alotaibi et al. where fog nodes were implemented for the integration of traffic lights with homes to reduce development complexity [25]. Smart traffic monitoring with fog and cloud computing was discussed to propose the value and necessity of fog nodes in traffic management [26]. A multilayer architecture was proposed where (a) sensing layer (b) fog layer (c) cloud layer and (d) services and apps were combined to create the Effective Framework for Traffic Congestion Problem [27]. Here, traffic light algorithm is part of layer 1 while image processing is the part of layer 2. Decision making was performed at layer 4.

A fog-based architecture was implemented on the iFog simulator to evaluate the performance using metrics tha include traffic efficiency, saving energy and reducing the latency, the average rate of traffic flow. Here, the execution time for the simulator was 4,548 seconds and claimed as better performance, more accuracy, low latency, and traffic efficiency.

Gamel et al. proposed Fog-Based Traffic Light Management Strategy (TLMS). They used iFog simulator to compare the efficiency of their architecture with other existing methods. Results was compared with ITMS Intelligent traffic management system for smart cities), AFNN (Analysis and Control of Intelligent Traffic Signal System Based on Adaptive Fuzzy Neural Network), CIVIC-E2 (Cooperative and Integrated Vehicle and Intersection Control for Energy Efficiency), and Intelligent traffic light under fog computing platform in data control of real-time traffic flow (ITL). However they claimed better performance of TLMS compared to all above methods [28]. The study done by Ning et al. (2019) showed how vehicular fog computing (VFC) can enable real-time and location-aware network responses for traffic management in smart cities. The article presents a three-layer VFC model and a VFC-enabled offloading scheme, both of which are validated using real-world taxi trajectory data. The study concludes by highlighting research challenges and open issues towards VFC-enabled traffic management[29]. Another study done by Brennand et al. (2017) introduces FOg RoutE VEhiculaR (FOREVER), a fog computing-based Intelligent Transport System mechanism that assists traffic management in Vehicular Networks (VANET) by detecting and recommending alternative routes to avoid previous congestion. Experimental results demonstrate that FOREVER achieves a reduction of 7.9%, 8.3%, and 7.6% in CO_2 emissions, stop time and trip time, respectively[30].

In addition to these recent frameworks, other efforts in this domain are listed in the Table 1.

Table 1. Smart traffic management frameworks.

Proposed Smart Traffic Framework	References
Design and implementation of a smart traffic signal control system for smart city applications	[31]
Real-time traffic light control system based on background updating and edge detection.	[32]
IoT-Based Smart Traffic Light System for Smart Cities.	[33]
Intelligent Traffic Signal Control System Using Machine Learning Techniques	[34]
Intelligent traffic light under fog computing platform in data control of real-time traffic flow	[35]

In the context of vehicular networks, fog computing can enable the use of intelligent transport systems that can detect traffic congestion and recommend alternative routes to vehicles. This can help to reduce the CO_2 emissions, stop time and trip time of vehicles, leading to more efficient and sustainable transportation in smart cities.

4. PROPOSED FRAMEWORK

The proposed framework has three sections. (1) edge nodes, (2) fog nodes, and (3) cloud nodes as shown in Figure 2. Edge nodes are the nodes in the IoT where the data is collected using cameras and sensors. Each lane of traffic has one camera and one sensor. There is an electronic display board after the installation point of cameras and sensors. After a fixed distance of display, there is a traffic signal, which is the end of the edge layer. Data collected from the edge later is transferred to fog nodes, where two nodes are designated for each camera and sensor. In the post fog node layer, there is a cloud layer where processed data is stored for a longer duration.

5. OPERATING PROCEDURE

The proposed framework shown in Figure 2 is for a single road with two lanes. It has 2 cameras, two sensors, one display board, two fog nodes, and a cloud layer with two nodes. Camera is directed towards the display board that captures the images of traffic ahead. Sensor is installed to capture the speed of the vehicles coming towards the display board. Images captured by the camera are transferred to fog nodes where they are processed [36] to detect the traffic congestion, and the decision is transferred back to the display board.

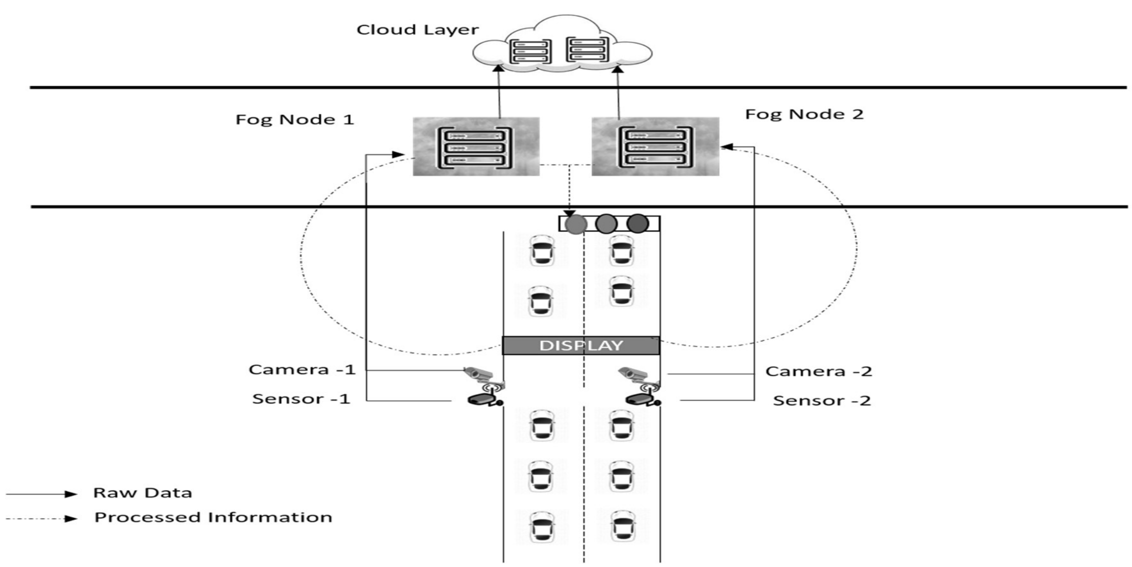

Figure 2. Framework For The Smart Traffic Management System Using Fog Nodes Architecture Complemented With Cloud Layer For Long Term Storage.

Fog nodes communicate with the cloud layer to transfer the processed data that includes the speed of vehicles and images of vehicular congestion. Two fog nodes installed are responsible for processing the data for each lane. Images of traffic conditions detect the vacant space or the number of vehicles on each lane of the road.

There are three paths for the flow of processed data from the fog nodes, as shown in Figure 2 (dashed line). Two cameras are installed to capture the images for each lane of the road. Similarly, two speed sensors are installed to calculate the speed of vehicles in each lane.

Processed data is transferred to cloud nodes for further processing if required and for long-term storage. However, the decision is based on the traffic congestion ahead and the speed of incoming vehicles, which is transferred from the fog nodes to the display board. This display would show the waiting time ahead at the traffic signal to all incoming vehicles so that they can manage their speed. The third piece of information transferred from the fog node is to the traffic light controller. Here, the traffic light controller receives the decision for the waiting time so that it can regulate the time duration for each traffic light (red, yellow, and green).

The cloud layer in this framework is meant to process and store the data for a longer time. However, it is observed that cloud layer communication on a frequent basis can impose latency and high network usage. This concern was addressed by implementing fog nodes in between the edge and the cloud layer. At the required time, more exhaustive processing can be performed at the cloud nodes and transferred back to fog nodes for better decision making. Moreover, the data from fog nodes is only transferred in batches after a certain fix interval.

6. HIGH RESOLUTION CAMERAS

This framework is composed of multiple cameras, and the number of cameras increases with the number of intersecting roads. Figure 2 shows the simplest scenario where there is only one road with two lanes. The framework shown in Figure 2 requires two high resolution cameras. The cameras are connected to the microcontroller. These cameras would be mounted low at the roadside to capture a clear image of the road sections. The resolution of the cameras would be a minimum of 704X480 pixels. However, a higher resolution 1920X1080 pixels would be preferred. The image processing would basically count the number of cars on the road to get an idea of how busy it is.

7. FOG NODES PROCESS

These cameras would take the image every 5 seconds and send it to fog nodes for processing. The flow of traffic would be detected in the regular interval images. The processing and handling of the images would be performed at different stages [37]. This includes (1) input of an image, (2) foreground detector, (3) image enhancement, and (4) image analysis. These steps are shown below: Capturing images every 5 seconds

- a) *Installation of the camera in a rigid position*

2) Fore ground detector

- a) *Detects the ground using Gaussian Mixture Models (GM- M)*
- b) *Take the RGB image and change it into gray scale*
- c) *Threshold optimization*
- d) *Conversion to binary images: replacing all the pixels with white or black based on the threshold*
- e) *Image segmentation*

3) Image Enhancement

- a) *Removal of noise*
- b) *Dilate process: this would enlarge the white areas.*
- c) *Road process: this would make the black areas enlarge*

4) Image analysis

- a) *Vehicle detection*
- b) *Vehicles counting*

The above image handling and processing would be performed on the fog node for each lane. The final image analysis would detect the number of vehicles and calculate the density of the traffic.

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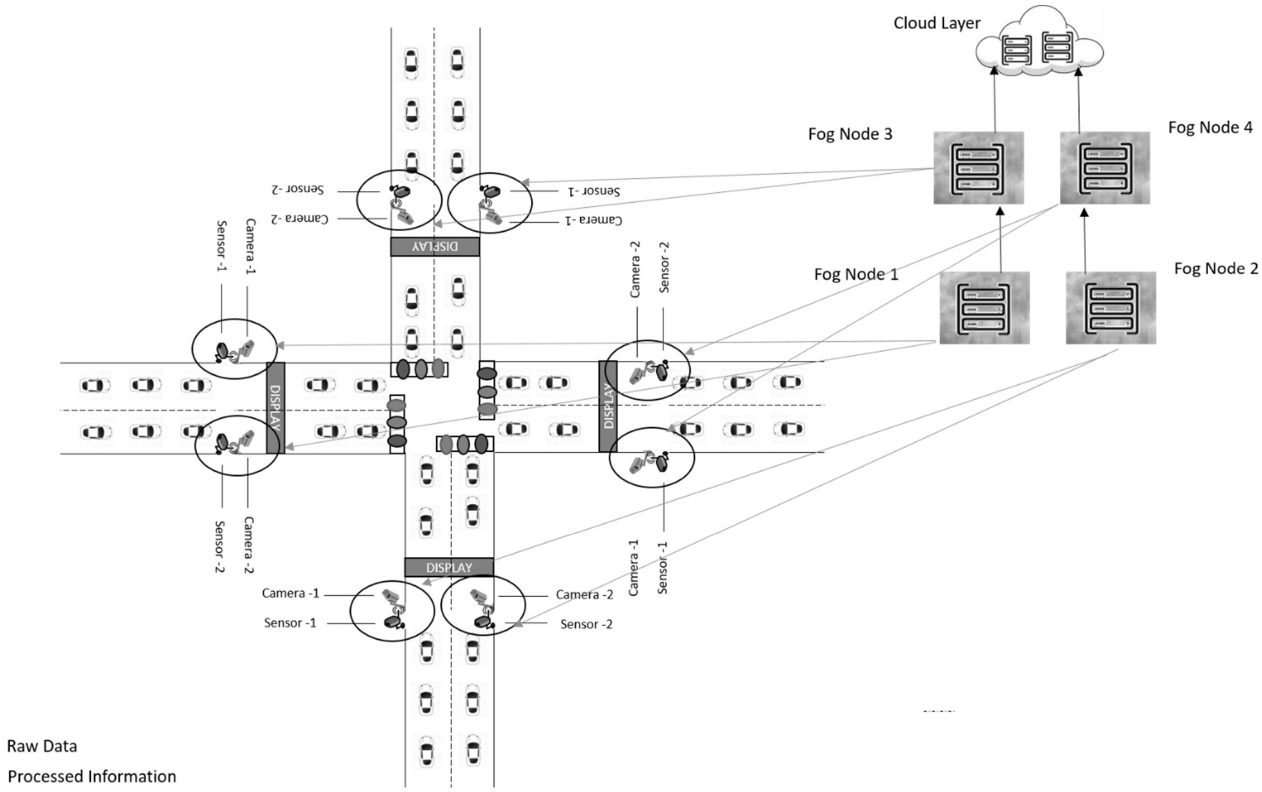

Figure 3. Multi-Road Traffic Signals And The Proposed Framework For The Smart Traffic Management System Using Fog Nodes Architecture Complemented With Cloud Layer For Long Term Storage.

8. MULTI ROAD ARCHITECTURE

In the multilane architecture, the roads are at the intersection points where there are multiple traffic signals. These signals have their respective cameras and speed sensors. Each road has 2 cameras and 2 speed sensors that send data to a single fog node. So, in this architecture, there are a total 4 fog nodes that collect the image and speed data for each road. Here, the data (image, speed) from each road is processed on fog nodes in context with the data from the other roads. These fog nodes are also interconnected and can evaluate the traffic load collectively. The display screen shown on each road would display the waiting time due to congestion ahead to control the speed of the traffic and avoid the additional congestion. Moreover, the processed data from each fog node would be transferred to a cloud node where a collective decision would be made for each traffic lights. So, the waiting and running time for each traffic signal on different roads would be different Further, it can be trained to predict the future congestion of any given day. The steps proposed to predict the congestion would be followed: based on the congestion and incoming traffic towards that road. This architecture would follow the same steps as mentioned in the earlier section for the single road. However, the processing of the data would be different at the fog nodes, as the data would be seen in coherence.

This architecture would provide a comprehensive traffic management and it can extend to any complex system of road signals. Here, the configuration of the fog node would depend upon the traffic load in the different location.

9. MACHINE LEARNING (ML) BASED PREDICTION

The traffic congestion and speed data accumulated on the cloud could be used to develop an ML guided algorithm. This data would be stored on the cloud for a longer period with reference to time, date, and day.

1) Capturing images every 5 seconds for each road.
2) Processing the images.
3) Estimate the volume of traffic (number of vehicles) on each road.

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4) Data training using supervised and un-supervised learning methods.
   a. *Categorize the volume of traffic data for every 1 hr grouped for each day.*
5) *Un-supervised method of clustering is employed to cluster the traffic congestion data based on day and time.*
6) *Deploy an ML algorithm to use the congestion data separately for every day of the week.*
7) *ML algorithm can predict the time for the input percentage of traffic congestion (10%, 20%, 30%, 40%, and 50% above).*
8) *Based on the congestion percentage, the selected duration time would be evaluated.*

Table 2. Percentage Traffic Congestion Of Mumbai Calculated For Average In 2021 For Each Day Of The Week.

Time -> Days	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00
Moday	60	64	62	57	51	58	49	54	63	77	83	68	46
Tuesday	57	63	63	59	53	50	51	56	65	79	85	70	49
Wednesday	60	66	65	61	55	51	53	58	57	81	89	74	51
Thursday	56	62	62	59	54	51	53	58	66	79	84	69	49
Friday	54	60	60	58	51	48	52	59	68	81	89	75	54
Saturday	37	48	61	68	67	64	65	70	73	78	83	71	55
Sunday	18	25	36	43	43	39	41	47	52	57	61	51	40

10. DATA IMPLEMENTATION

Traffic data of Mumbai is collected from https://www.tomtom.com/en_gb/traffic-index/mumbai-traffic/. This data has average congestion in 2021 for every day of the week (Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, and Sunday) for each hour. Table 2 shows the tabular data for the week of 24 hrs. The data is shown in Table 2, calculated for the average in 2021. However, for the ML model preparation, data for each frame (every five minutes) is required. Here, in Table 2, it is shown that on Monday, at 15:00 hours (3:00 PM) in the daytime, there is the lowest traffic congestion with 49%. Similarly, for Tuesday, Wednesday, Thursday, and Friday, the lowest congestion time was 14:00 hrs (2:00 PM). This may indicate a trend of lower traffic congestion between 14:00 and 15:00 hrs in the daytime. Moreover, on Saturday and Sunday, 09:00 hrs (09:00 AM) is the lowest congestion time as shown in figure 4. These trends can be more comprehensively accommodated using the detailed capturing of vehicle images and speed framework illustrated in Figure 2 and Figure 3. Big data accumulation using the current proposed method can allow the application of ML for precise congestion prediction.

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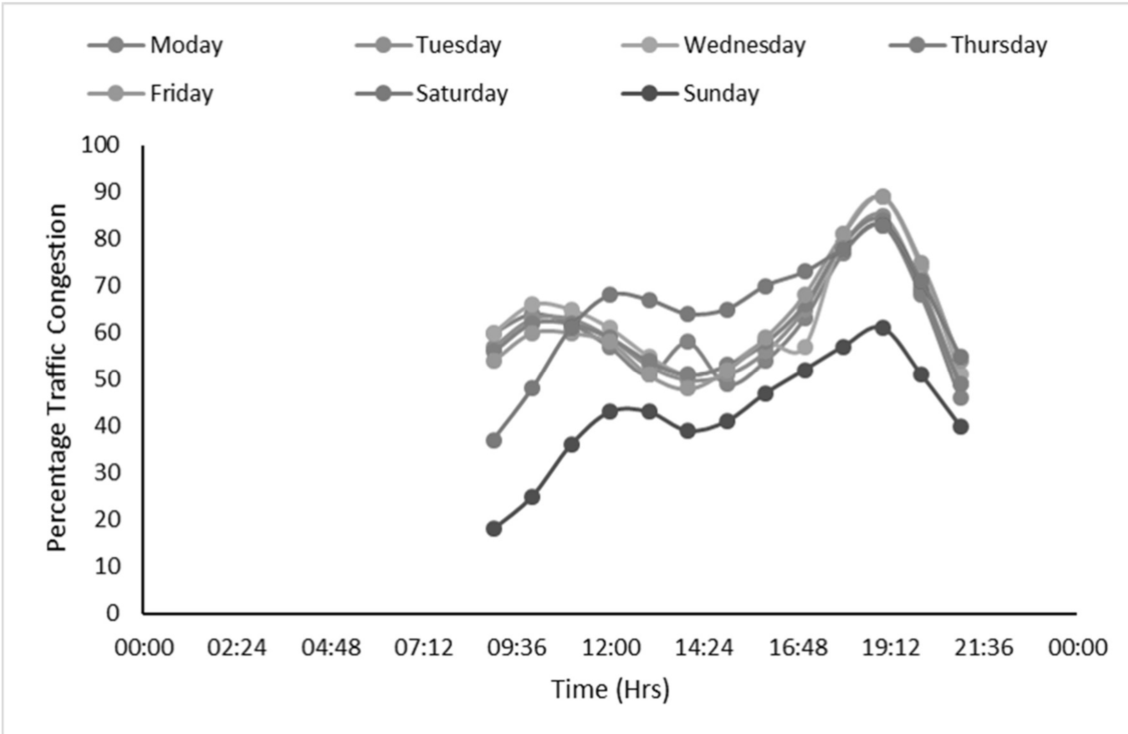

Figure 4. Mumbai Traffic Congestion Data With Respect To Time Collected From Https://Www.Tomtom.Com/En_Gb/Traffic-Index/Mumbai-Traffic/.

11. SECURITY ARCHITECTURE

Fog computing is derived from the cloud computing and, thus, it also carries security concerns. Security of the framework would be maintained at various layers, handling different types of security.

- **Authentication:** In the presented framework, authentication of all units applied in the framework would be maintained. In fog computing, entities must be registered with the registration bodies. In the traffic management system, this authority is the Traffic Control Office (TCO). Each device used in this framework would be registered with TCO. A pair of public-private keys would be generated for the device and fog server. Devices would be given an ID from TCO as unique identification.

dk_i: device public key
fsk_n: fog node private key
dID: device id

Devices collect the images/speed/etc. from the running traffic. Data would be encrypted using the public key of the device. Later, the data would be transferred to the fog node. Device ID would be confirmed by the fog node. If the confirmation fails, the data would be rejected. If the confirmation is approved, then encrypted data would be decrypted using the fog node's private key. Similarly, every vehicle should be registered with the TCO. Every time data is transferred from the devices to the fog node, its ID would be verified on the fog node first and only a valid registered ID would be considered for the data passing. First time ID of all these devices would be given to TCO for registration [38].

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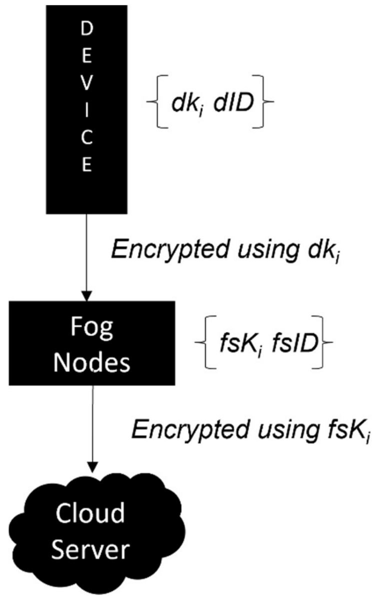

Figure 5. Authentication And Secure Data Transfer Using Public-Private Key Architecture.

- **Encryption/Decryption:** Encryption of the data was performed using ciphertext policy attribute-based encryption for the text data. This can also be applied if the proposed framework would be modified in terms of adding the connection between vehicles using smart phone devices. Ciphertext-Policy Attribute-Based Encryption with a concealed access control policy allows data owners to distribute encrypted data through fog/cloud storage with authorised users while concealing the access control rules.

The proposed architecture depends heavily on the vehicle's images. These images would also contain private information. Thus, it is necessary to use image encryption and decryption while the images are transferred in the network. Vehicle image data would be encrypted using watermarking technology. Watermarking technique would be applied from Zhong et al. work [39]. In general, principal, the watermark (w) is embedded in the cover image (c) which is vehicle's image in this application. The embedded watermark (w*) is extracted by the receiver from the marked images (m*). In the traditional method, the cover image (vehicle) is projected on its several feature spaces. Later, the watermark (w) is embedded in this projection space. Further, the marked image (m*) is projected on the same feature space to extract the information from the watermark. However, the embedding and extraction involved in watermarking is highly manual in the traditional approach. This makes the overall task challenging and error prone. The architecture proposed by Zhong et al. replaces the manual process with the deep learning method for embedding and extraction. This method would be implemented in the image encryption when it's transferred to fog nodes or even to the smart devices. This would allow us to protect the images in the network.

10. CONCLUSIONS

This study proposes the application of fog computing for smart traffic management. The proposed framework can estimate the congestion and regulate the traffic. The quantification of vehicular traffic is determined by the traffic density metric, denoting the quantity of vehicles present within a given area. The aforementioned framework bears resemblance to that of cloud computing. However, the duration of information transfer is protracted, thereby impeding traffic management. This, in turn, results in a reduction of work hours due to increased travel time, ultimately impacting the helath and lifestyle. The present study proposes employing a framework that has been recommended by prior research studies as a means of mitigating traffic congestion. Fog computing, used in this framework, can retrieve the traffic data (image and speed) of the vehicles in a short time compared to the cloud system. Here, fog can process the data and handle the latency limitations of the cloud. Processed data can be stored in the cloud for longer storage. This framework suggested a waiting display board that receives the final decision from the fog nodes and shows the waiting time for incoming vehicles. This would allow the incoming vehicles to speedup or speed down as per the message displayed on the electronic board and avoid the congestion at the signal. In addition, this framework also implemented the networking of traffic lights with the fog nodes. The waiting and running time for each signal would be calculated on the fog node and sent to the traffic signals. Lastly, this model proposed the use of traffic data to build an ML model that can help the community predict the lowest traffic congestion time for a given day.

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