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Optimizing Latency in Air Quality Monitoring Architecture by Fog-Enabled Technology

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Abstract

In recent years, the rapid rise of the population and urbanization have raised the issue of air pollution. Because of its impact on human health, air quality monitoring is a crucial problem. Air pollution impacts our daily lives and quality of life. It presents a threat to the planet's environment and quality of life. Because industrial operations have grown in recent years, there is a clear need to monitor air quality. People must realize how their actions affect the quality of the air. With advances in sensing and embedded technology, the Internet of Things (IoT) has emerged as a cost-effective alternative to costly and stationary air quality monitoring stations for implementing air quality monitoring systems (AQMS). By developing an air pollution monitoring system, it will be possible to count the main pollutants and their sources with accuracy. Data is processed and cleaned close to IoT nodes' ends in the Fog computing paradigm, which is effective for addressing these problems and enhancing the quality of service (QoS) of IoT networks. The major reason for using fog computing in the suggested solution is to reduce network use and latency for the entire air pollution monitoring system. To solve the inadequacies of current methods, we suggest a three-phase pollution monitoring system. To demonstrate the effectiveness of the suggested technique for lowering latency and network consumption, the outcomes of simulations in iFogSim have been compared to those of the system's cloud-based application for monitoring air quality. Experimental findings demonstrate a considerable reduction in delay with the recommended fog-based deployment of an effective air quality monitoring system.

Keywords: Fog computing, Air monitoring, Fog-based air monitoring System, Latency optimization.

1. Introduction

The rapid advancements in information and communication technology are attracting people to urban areas, leading to the overcrowding of these cities. A sizable portion of the population has moved into cities, which has resulted in a massive increase in the number of automobiles utilized for daily commutes. This impacts the ambient conditions in places such as shopping centers, hospitals, schools, offices, and so on, potentially affecting people's health and productivity at work. It is decisive to supervise the air quality. Due to the massive industrialization and urbanization that is occurring throughout the world, air quality levels are dropping at a never-before-seen rate, which poses a major hazard to both individuals and the environment. This raises the concern of real-time air quality monitoring and forecasting [1].

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When considering the detrimental effects of pollution on people, one in eight of all worldwide fatalities in 2012 were caused by air pollution, which resulted in 7 million unexpected deaths globally [2]. There are several ways that pollution affects human health. In addition to a respiratory condition, hospitalization for heart or lung conditions might worsen their conditions, including bronchial asthma, bronchitis, and respiratory illnesses. The price of pollution control equipment may become a serious problem for governments if air quality continues to deteriorate [3]. A high level of air contamination directly impacts an individual's physical condition, leading to an increase in associated symptoms and diseases. On the other hand, residents of cities demand a higher standard of living, which, among other things, raises expectations for good air quality. When considering enticing visitors and investors who would further boost the city's economic growth, high air quality is crucial to ensuring the city's future development [4].
According to the Ministry of Health (WHO), 7 million people per year pass away due to air pollution, and 90% of people on earth currently breathe polluted air. The harmful impacts of pollution on health include heart disease, lung cancer, and stroke. Current global air pollution issues, such as ozone [6–7], demonstrate this. The ongoing increase in vehicle usage and worsening driving conditions make these pollution reduction measures even more urgent (traffic congestion). As a result, one of the first things local governments should do to address their environmental goals and difficulties (such as national emission limits or air quality standards) is to implement trustworthy emission systems that can reliably measure air pollution and identify pollution peaks [8]. IoT technology offers a practical approach to addressing the issue of environmental contamination. Air pollution's financial toll: A joint investigation between the World Bank and the Institute for Health Metrics and Evaluation (IHME), strengthening the Financial Case for Activity, seeks to estimate the costs of unforeseen losses linked to air pollution to strengthen the action case and promote fundamental leadership about rare assets.
In 2013, an estimated 5.5 million people died from diseases linked to contaminated outdoor and indoor air, resulting in human suffering and a decline in economic growth [9]. Due to fast industrialization and an increase in the number of automobiles, air pollution in developing nations is rapidly rising. As a result, many governments are creating legislation to reduce air pollution. This, in turn, is leading to a surge in demand for air quality monitoring equipment in nations like China and India, opening up attractive opportunities for the industry's stakeholders [10].
The cloud simplifies the AQI category through the use of sensors for air quality monitoring. A major issue with the system is timely updating, though, as directly connecting the sensors to the cloud introduces latency that cannot be tolerated for applications that need quick turnaround times. We therefore suggest monitoring the air quality using fog to address the drawbacks of cloud-based approaches in ambient air monitoring systems. This study offers the following three contributions:

1) A three-tiered fog-based architecture has been projected for an efficient air quality monitoring system, with the intermediate tier utilizing the fog computing concept. The fog nodes process sensor data and display the output on the LED.
2) The suggested fog-based design considers latency and network use. While this is happening, the data is sentenced and processed quickly, reducing latency and network use. Because of their decentralized nature, the fog nodes' coordination provides information at the right moment, saving time for the timely delivery of air pollution levels.
3) The usefulness and competence of the suggested fog-enabled air quality monitoring structural design are extensively evaluated through simulations. When contrasted to a cloud-based solution, experimental tests reveal that the air quality monitoring system's network utilization and latency are much lower.

1.1Fog Computing

Hundreds of billions of things connect to the IoT via wired or wireless communication. These devices generate vast amounts of data, typically uploading it to the cloud for analysis. When data is processed in the cloud, it takes a long time, which is inconvenient for real-time applications like healthcare. As a result, providing real-time services in cloud computing is a huge difficulty. Because of the large latencies inherent in cloud computing, the notion of fog computing comes into play. Physical devices communicate data to the cloud in the IoT architecture. Service is delivered to end-user apps after the particular processing of these data. Fog computing has a decentralized architecture that allows operations to run close to the edge of devices, reducing service delay. A fog serves as a connection between the sensor and the cloud. Cisco coined the term "fog computing. According to Cisco, the Internet of Everything combines community, processes, data, and things to turn information into action, making networked relationships more relevant and useful than ever before. Over the next decade, the Internet of Things has had a significant impact and has the potential to bring $1.9 trillion to cities around the world. Cloud computing services are expanded by Fog from the center to the edge networks [11].

Fog computing is a tiered framework that allows clients from all around the world to access a common pool of flexible computing resources. Under this concept, fog nodes (physical and virtual) exist among sensitive end-devices and centralized (cloud) services, allowing for the development of decentralized, delayed apps and services. Fig. 1 represents the structural design of fog computing, and Table 1 discusses the assessment of cloud and fog computing.

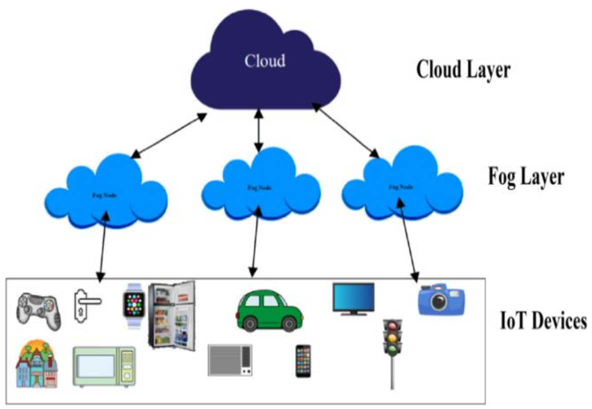

Figure 1: Structural design of Fog Paradigm

Table 1: Assessment of Cloud and Fog Computing [12]

Requirements	Cloud Computing	Fog Computing
Latency	More	Less
Safety measures	Less security	High Security
Ability	Not give any data reduction	The volume of data delivered to cloud computing decreases with this technology
Delay	Jitter High	Very low
Communication approach	IP network	Wireless technologies, as well as wired communication and part of the IP networks
Server nodes	only some	Large
Location Awareness	No	Yes
The range between the server and client	Multi hops	One hop
Geo-distribution	Centralized	Distributed

Fog computing may be the most effective method for offering a dependable and trustworthy solution to a large number of IoT clients. Numerous IoT applications gain when fog computing and IoT are combined [13]. Fog computing, discussed by Alli and Alam [14], is a type of distributed infrastructure system that makes data processing, storage, and calculation easier. Reduced time spent gathering and analyzing data from various areas' databases is another crucial benefit of incorporating fog computing into the system. Instead of using the cloud, fog has emerged as a way to provide IoT real-world applications [15]. When it comes to performing as expected by developing paradigms, fog computing outperforms cloud computing. [16]. Fog increases IoT efficiency by establishing a connection between the cloud layer and the IoT solutions' end devices. [17]. As data approaches the network's edge, Fog, also known as Fogging, strives to improve data processing, intelligence, and gathering. This makes it simpler to deliver computer-related services more effectively in a dispersed computing environment, bringing them much closer to the integrated smart devices that make up a significant portion of the IoT [18]. A cutting-edge generation of apps and services has expanded as a result of Fog, a revolutionary network edge technology [19]. Fog computing is a unified strategy for reducing latency, which is crucial for time-sensitive applications in particular. [20]. With fog computing, all of the features of the cloud are made more accessible to end devices [21]. In order to do this, we have put forth a system that can assess a range of air quality parameters and give users valuable data to understand the air they are breathing. In addition to categorizing the data as healthy or unhealthy, the system is useful for offering insights that may be put into practice. In order to implement the suggested system, air-quality-based Internet of Things (IoT) nodes were built. These nodes are able to detect the presence and concentration of toxic gases and then transfer the collected data to the fog layer for quick analysis and better outcomes. The IoT nodes, which include air quality sensors and communication modules for data transfer, are the main components of the proposed systems. A sensor, fog computing, and a cloud layer make up the three-tier architecture of the suggested fog computing-based air quality monitoring system.

The rest of the paper is organized in such a way that Section II highlights the latest study on air quality monitoring systems, while Section III discusses the experimental design, and Section IV includes a summary of the findings. The work is accomplished in Section V, which also outlines the route for additional research.

2. Related Work

The architecture for effective decentralized fog-based air quality monitoring employs layered data analysis and processing. The authors find that Fog is an essential and valuable technology that is ideally suited for applications that generate massive amounts of data that are required to be evaluated earlier than performing any fundamental or advanced analysis. Additionally, it is readily able to manage data locally, near IoT sensors. This method enhances reaction time by reducing the data transmission to the cloud [22]. Air quality measurement is a crucial problem that directly impacts individual wellbeing. In this work, an air quality monitoring system was constructed using microprocessor-based hardware and cutting-edge IoT techniques. In this paper [23], the author suggests a model that could monitor several gases and particular chemicals in addition to humidity and temperature. Methods were employed to manage cross-sensitivity issues and prevent transitory sensor errors. This study recommends enhancing a sensor-based air monitoring system with Arduino technology. When did you gather data from various air monitoring stations? The author of this study [24] provides a systematic mapping analysis with a well-defined step process for determining and evaluating the state of research on smart city IoT-based air pollution monitoring systems. The study includes recommendations, some of which have already seen implementation. We assess and contrast these methods based on the different mapping attributes, and we then highlight some of the challenges involved in putting in place air contamination monitoring systems in the context of smart cities. Researchers are developing a way [25] to monitor the air quality inside buildings using the Internet of Things.

They investigate AQI monitoring systems, summarize earlier studies, and compile data from three databases in order to encourage studies on AQI that use the Internet of Things and synthesize publications about IAQ leveraging IoT. This project's goal is to create an esp8266-based air excellence monitoring system [26]. Customers can therefore check the air quality using a smartphone hooked up to ESP8266 Wi-Fi. Therefore, you can always check the air conditioning.

Researchers are developing a way [25] to monitor the air quality inside buildings using the Internet of Things. They investigate AQI monitoring systems, summarize previous studies, and compile data from three databases to stimulate research on AQI using the Internet of Things and synthesize publications about IAQ leveraging IoT. This project's goal is to create an esp8266-based air excellence monitoring system [26]. Customers can therefore check the air quality using a smartphone hooked up to ESP8266 Wi-Fi. Therefore, you can always check the air conditioning.

To support IoT-based design for AQMS, the authors [27] provide an analysis and comparison of infrastructure and application layer protocols. We also examine current systems and classify them according to the deployment technique used. In this work, the author [28] implements a system for smart cities using a five-step methodology, constructing a systematic mapping analysis to identify and assess the current state of research on IoT-based air contamination analysis. According to the Malaysia Air Pollution Index, we have reported on an efficient application of the IoT for air pollution monitoring (API).

The minimum outlay and synchronized system can track common air quality contaminants such as carbon monoxide gas, particulate matter (PM2.5 and PM10), as well as ambient temperatures and humidity [29]. The authors [30] suggested installing IoT-based systems to detect air quality factors at both indoor and outdoor locations. The systems have also been evaluated at an assortment of service levels at inside and outside locations. In this proposal, the authors [31] outline the hardware development layer for a device capable of monitoring the concentrations of various air pollutants. To create a cloud-Fog-integrated IIoT network, authors [32] were driven to connect Fog computing with cloud-based IIoT. The author proposed the use of a genetic algorithm to address the inhibited optimization problem (RCGA-CO), which aims to resolve the issue of work overloading and balancing in the decentralized cloud-fog network, thereby achieving extremely low service response latency in the CF-IIoT. Large-scale applications that are broken up into linked application modules may be architecturally deployed over the nodes based on their susceptibility to latency in order to make the most excellent use of the capabilities of the Fog nodes. We present an application module methodology for the Fog environment in this study that takes service delivery latency variations and the quantity of transmitted signals that need to be handled per unit of time for various applications into account. The proposal's [33] purposes include ensuring applications' quality of service (QoS) in order to adhere to service delivery restrictions and optimizing resource utilization in the Fog environment. In this research, we introduce a unique distributed resource allocation technique that streamlines the deployment and integration of diverse applications within an IoT environment. The algorithm determines [34] how to map IoT applications at the network's edge and how to dynamically move application components so that the Service Level Agreement (SLA) is met. For properly distributing resources to modules in a Fog network, we explore scheduling algorithms and variables in this research and present the greedy knapsack-based scheduling (GKS) algorithm. As a common FC simulator, iFogsim was used to mimic our suggested technique. The results [35] show that the FCFS, synchronized, and delay-priority algorithms are not as good as the GKS when it comes to how much energy they use, how hard they are to compute, and how long the sensors last. In this paper [36], the author has chosen gateways as potential deployment locations for fog nodes. The gateway gathers information from intelligent sensors, but it is incapable of preprocessing or making decisions. As a result, the gateway has been upgraded to have fog capabilities and given the moniker Fog Smart Gateway (FSG). Virtual machines (VMs) are used to handle IoT traffic by implementing distributed Fog nodes, and the nodes deployed were adjusted to minimize overall latency caused by traffic collection and processing. The method is implemented by the author, and its effectiveness is assessed by a network of WSN430 IEEE 802.15.4-enabled open nodes. On larger sizes and with more varied topologies, a simulation model is verified and employed for performance evaluation.

The authors show that the proposed technique [37] outperforms both traditional centralized and even distributed alternatives, maintaining average access latency below the predetermined threshold. This study proposes a unique Intelligent Multimedia Data Segregation (IMDS) method that separates multimedia data and a model for calculating total delay using machine learning [38]. Using the simulated results, we improved the quality of e-healthcare services, achieving 92% classification accuracy for the method and a 95% decrease in latency over the previous model. The author provided a unique cure for the stated problem. In an FC context, it blends a logical model with a hybrid fuzzy-based reinforcement learning technique. Reducing high latency between cloud servers, end users, and healthcare IoTs is the aim. The writer [39] suggested a smart FC model and algorithm that uses a fuzzy inference system, reinforcement learning, and neural network evolution methods to choose and assign data packets in an IoT-FC setting. To address the load balancing issue of the distributed cloud-Fog network and achieve exceptionally low service response latency on the CF-IIoT network, the author recommends [40] the use of the real-coded genetic algorithm for constrained optimization problem (RCGA-CO) strategy. Given the CF-IIoT network architecture's unreliability, the solution we provide for task re-allocation and retransmission to improve the average service latency is critical.

According to this paper, researchers [41] concentrate on reducing the application's overall latency when deploying modules on Fog nodes. We offer both precise and approximate solutions to the module placement challenge. Both CPLEX and an iFogSim-simulated fog environment were used for the experiments. Outcomes demonstrate the potency of our chosen strategy. Researchers propose a decentralized latency-aware data processing model where FC-capable GWs enthusiastically share information about their distribution and storage capabilities, stochastically transferring data to other GWs or the cloud only when there is a limit in local processing or storage. In this paper [42], a DLA-DP-enabled IoT network is evaluated using in-depth simulations and modeled as a network of M/M/m/B queuing systems. Improvements made possible by the DLA-DP paradigm include faster gateway processing, quicker system response times, and more efficient buffer occupancy. This paper presents [43] a modified genetic algorithm (GA) implementation as a heuristic method to plan the IoT queries to reduce the overall latency. The GA is tested in a simulation that considers the flexible environment. The suggested technique is built on an oscillating optimization method that produces results that are very close to optimal with a minimal amount of complexity. To demonstrate [44] how the suggested algorithm performs when compared to the enumerative approach, numerical results are given. Comparing three-layer decentralized IoT-fog-cloud computing to only fog and cloud computing systems, the latency benefit is calculated.

3. Dataset Collection

In order to demonstrate the proposed approach, we analyzed a publicly available air pollution dataset. The dataset contains data from different sites for the period 2013–2017. The air-quality data are from the Beijing Municipal Environmental Monitoring Center. The meteorological data at each air-quality site is matched with the nearest weather station from the China Meteorological Administration. The time period is from March 1st, 2013 to February 28th, 2017. PM2.5: PM2.5 concentration (ug/m^3), PM10: PM10 concentration (ug/m^3), SO2: SO2 concentration (ug/m^3), NO2: NO2 concentration (ug/m^3), CO: CO concentration (ug/m^3), O3: O3 concentration (ug/m^3).

Table 2: Dataset of Air Quality

No	Year	Month	Day	Hour	PM2.5	PM10	SO2	NO2	CO	O3	TEMP	PRES	DEWP	RAIN	WD	WSPM	Station
1	2013	3	1	0	4	4	4	7	300	77	-0.7	1023	-19	0	100	4.4	121
2	2013	3	1	1	8	8	4	7	300	77	-1.1	1023	-18	0	115	4.7	121
3	2013	3	1	2	7	7	5	10	300	73	-1.1	1024	-18	0	100	5.6	121
4	2013	3	1	3	6	6	11	11	300	72	-1.4	1025	-19	0	120	3.1	121
5	2013	3	1	4	3	3	12	12	300	72	-2	1025	-20	0	115	2	121
6	2013	3	1	5	5	5	18	18	400	66	-2.2	1026	-20	0	115	3.7	121
7	2013	3	1	6	3	3	18	32	500	50	-2.6	1027	-19	0	101	2.5	121
8	2013	3	1	7	3	6	19	41	500	43	-1.6	1027	-19	0	100	3.8	121
9	2013	3	1	8	3	6	16	43	500	45	0.1	1028	-19	0	100	4.1	121
10	2013	3	1	9	3	8	12	28	400	59	1.2	1029	-19	0	115	2.6	121
11	2013	3	1	10	3	6	9	12	400	72	1.9	1028	-19	0	100	3.6	121
12	2013	3	1	11	3	6	9	14	400	71	2.9	1028	-21	0	115	3.7	121
13	2013	3	1	12	3	6	7	13	300	74	3.9	1027	-20	0	100	5.1	121
14	2013	3	1	13	3	6	7	12	400	76	5.3	1026	-19	0	120	4.3	121
15	2013	3	1	14	6	9	7	11	400	77	6	1026	-20	0	120	4.4	121
16	2013	3	1	15	8	15	7	14	400	76	6.2	1026	-19	0	101	2.8	121
17	2013	3	1	16	9	19	9	13	400	76	5.9	1026	-18	0	100	3.9	121
18	2013	3	1	17	10	23	11	15	400	74	4.3	1026	-19	0	101	2.8	121
19	2013	3	1	18	11	20	8	20	500	70	3.1	1027	-18	0	101	2.1	121
2	20	3	1	19	8	14	12	30	50	6	2.3	102	-18	0	11	2.8	121

0	13								0	0		8			5		
2 1	20 13	3	1	20	11	17	13	33	60 0	5 5	1.7	102 9	-17	0	11 5	2.1	121
2 2	20 13	3	1	21	12	18	16	35	50 0	5 0	0.6	103 0	-17	0	10 7	0.8	121
2 3	20 13	3	1	22	15	19	21	57	70 0	3 2	0.9	103 1	-17	0	10 7	1.8	121
2 4	20 13	3	1	23	24	24	26	54	60 0	3 6	-0.2	103 1	-17	0	10 7	1.4	121

3.1 Preprocessing of Dataset at Fog Layer

The dataset has a huge quantity, thus a randomly selected 35064 samples. The AQI features of the six gases, i.e., PM2.5, PM10, SO2, NO2, O3, and CO, are selected for further data analysis. The missing samples in the dataset are interpolated with average values. Once the dataset is preprocessed, K-means clustering is used. The primary reason for choosing K-means and Secondly, K-means is frequently applied to track environmental changes. Cluster analysis is one of the most important research directions in the field of data mining. Unlike other data mining methods, clustering allows for the completion of data classification without prior knowledge.

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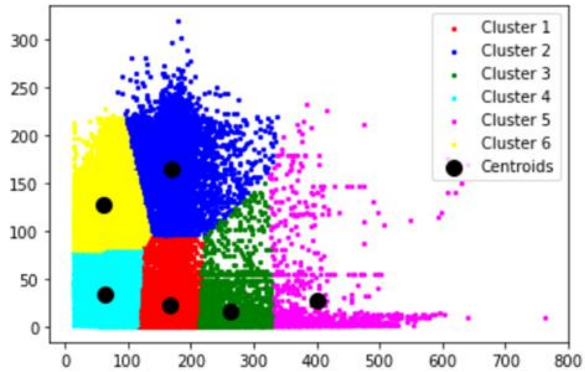

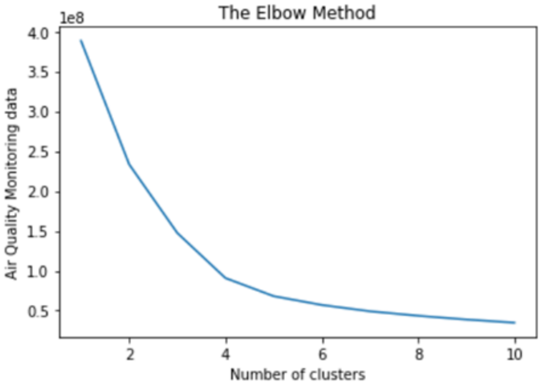

Figure 2: Elbow diagram **Figure 3:** PM2.5, PM10, SO2, NO2, CO and O3 gases

The primary reason for selecting K-means is that K-means is frequently applied to track environmental changes. Cluster analysis is one of the most important research directions in the field of data mining. Things are clustered and people are grouped; compared with other data mining methods, clustering can complete the classification of data without prior knowledge with six clusters. After deciding the number of clusters, the subsequent step is to convert the pollutant gas concentrations to the Air Quality Index (AQI) and organize them as Good (G), Moderate (M), and Unhealthy for sensitive groups (Usg), Unhealthy (U), Very Unhealthy (VU), and Hazardous (H) based on the AQI ranges.

3.2 Classification of Air Quality Data at the Fog Layer

Once an air pollutant has been converted to an AQI, the whole data set has a consistent format that is independent of the air pollution measuring unit. In general, the AQI for each air pollutant is determined, and the air pollution with the highest AQI determines the environmental condition of that specific instance. Based on this, it is possible that the entire dataset will be categorized into one class, resulting in a class imbalance problem in supervised classification. We created an alternate approach for this aim, using clustering to aggregate the associated data (organized into six classes) and the resulting clusters as classes, namely Good (G), Moderate (M), and Unhealthy for sensitive groups (Usg), Unhealthy (U), Very Unhealthy (VU), and Hazardous (H). These classes may be employed to train supervised classification models. Support Vector Machines (SVM), AdaBoost, Decision Tree (DT), K Nearest Neighbour (KNN), and Random Forest Bagging Classifier are among the classifiers used to classify the preprocessed dataset. We chose SVM because of its ability to discover intricate correlations between data samples without requiring any complicated adjustments [45].

For the creation of the training and test sets, the dataset is divided into 70:30 ratios. On the test set, SVM had the greatest performance with an accuracy of 99.97%, while DT, RF, and BG provided an acceptable performance on the clustered dataset. Adaboost exhibits the worst performance, with an accuracy of 94.02%. To assess the effectiveness of these models, metrics including accuracy (Acc), precision (Pre), recall (Rec), and F1-Score (F1-Sc) are generated. The formulae for these metrics are shown in equations (1) through (2), where TP stands for true positive, TN for true negative, FP for false positive, and FN for false negative. Table 2 displays the assessment findings of the various classifiers on the dataset.

$$\text{Accu} = \frac{TP + TN}{TP + TN + FP + FN} \tag{1}$$

$$\text{Reca} = \frac{TP}{TP + FN}$$

$$\text{Prec} = \frac{TP}{TP + FP}$$

$$\text{F1-Sc} = 2 * + \frac{\text{prec} * \text{Reca}}{\text{Prec} + \text{Reca}} \tag{2}$$

Table 3: Accuracy rate of dataset

Accuracy on Test Set	Classifier Accuracy
AdaBoost	94.02
KNN	99.68
SVM	99.97
DT	99.74
RF	99.88
BG	99.79

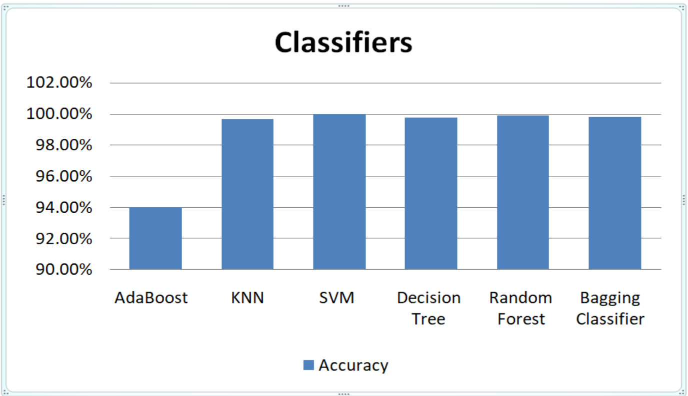

Figure 4: Accuracy Graph of Classifiers

Table 4: F1-Score on Test Set

	G	M	Usg	U	UV	H
AdaBoost	100	89	91	99	10	98
KNN	100	100	99	100	99	100
SVM	100	100	100	100	100	100
DT	100	100	99	100	99	99
RF	100	100	99	100	99	99
BG	100	100	100	100	100	100

Table 5: F1-Score on Test Set

	G	M	Usg	U	VU	H
AdaBoost	99	94	81	99	18	94
KNN	100	100	99	100	99	100
SVM	100	100	100	100	100	100
DT	100	99	99	100	99	100
RF	100	100	100	100	100	100
BG	100	100	100	100	100	100

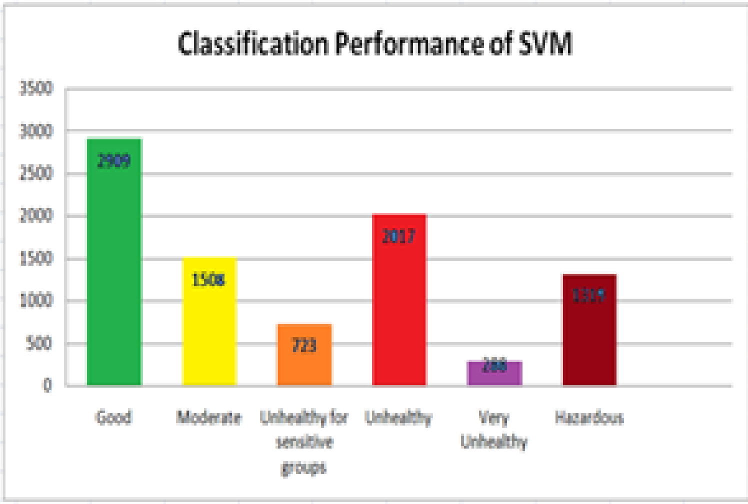

Figure 5: Performance of SVM

On the basis of this data set, we are improving latency in the form of data transfer in the area of air quality monitoring using IoT and fog computing.

4. Methodology, Tools, and Experimental Setup

The proposed work provides a three-tier architecture for air quality monitoring. The architecture consists of core fog computing technology to reduce the latency of computation. Figure 6 represents the proposed three-tier architecture, which consists of three layers named sensor layer, fog layer, and cloud layer. All the layers are interconnected. The first layer is the sensor layer, which continuously gathers the environmental data from various sensors and sends it to the fog layer, where such data is processed, and then the data is passed to the cloud layer so that it can be processed, and then the data is passed to the cloud layer so that it can be stored in a central database.

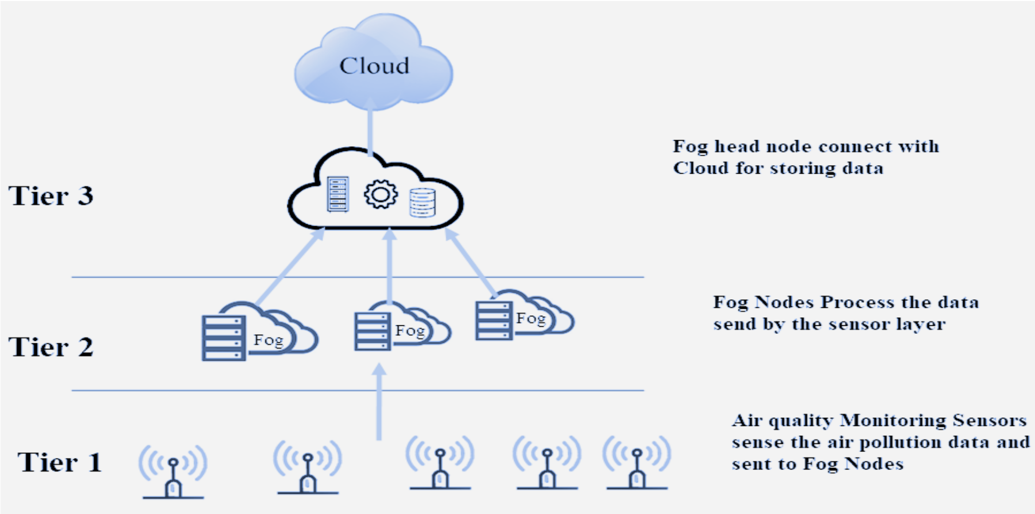

Figure 6: Three tier structural designs for Fog enabled Air Quality Monitoring System

The recommended architecture's sensors are in charge of figuring out how much air pollution there is. Data processed at the Fog layer using the observed data; the result is shown as an AQI. The city deploys several sensors at various locations. In the recommended structural design, the router served as a middleman between the sensors and the fog node. Fog nodes located in the city work together to provide information on the air quality. Although cloud computing can process and store data for a long time, frequent connections for data access and transfer can consume a lot of network capacity, which has a detrimental impact on other applications. The fog node's intermediate layer minimizes the delay. In the shown architecture, the fog node is where the picture processing and storage operations take place. There is two-way communication between the cloud and the fog node. The processed data is sent to the cloud after a set number of instances have been maintained there for a long time. Figures 6 and 7 show two examples. Figure 6 illustrates the architectural layout for the envisioned locations of the fog-based air quality monitoring systems. What would happen if there was only one region, as shown in Figure 6? Only one Fog node will be installed if there is only one region, and it will transport the data to the cloud server for long-term storage. Figure 7, on the other hand, shows the architecture for several locations, with every Fog node linked to a distinct cloud server. Each fog node will be associated with the main cloud server. In this scenario, each Fog node's latency and network use will remain constant, but posting and retrieving data from a centralized cloud server would take more time and use more network resources. The components of the intended architecture are discussed below:

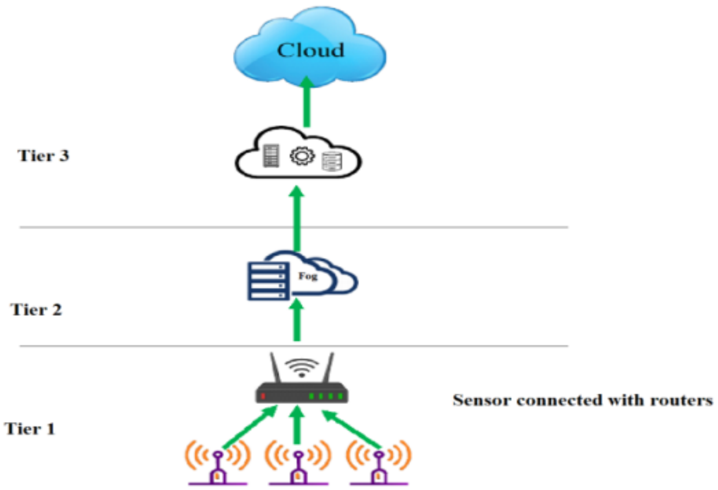

Figure 7: Structural design of the Air quality monitoring system for single area with three sensors

4.1 Sensor Layer

A number of sensor nodes comprise the wireless sensor network air pollution monitoring system (WAPMS), which also includes a communications network that allows data to be transferred to a server. Through the network, data for the sensor network is sent to one or many access points, which subsequently send it to a server. Data is collected independently by each sensor node. In the IoT, the bottom layer is primarily where the sensors and network connectivity are found. These sensors' primary purpose is to gather information about the environment. The development of Internet of Things nodes with a microcontroller and numerous sensors to sense air pollutants, including CO2, NO2, O3, and SO2, is part of the sensor layer. To deliver data to the fog layer, the microcontroller is attached to a network interface, such as LoRaWan, GSM, or WiFi. Based on the size of the metropolitan center to be observed and the level of coverage needed, the configuration of IoT nodes in the sensor layer may be stationary or movable. On initiatives like city buses, sensors may be fitted to assess pollution very precisely. These buses can offer all-encompassing exposure for the air data because they run on a timetable throughout the day throughout the city. These buses can have sensors installed that can produce a huge amount of data often. The data generated by this layer will first be routed to the Fog layer for pre-processing before being transmitted to the cloud.

4.2 Fog Layer

In addition to being able to respond to requests in milliseconds, fog nodes are therefore capable of collecting real-time data from Internet of Things devices, running applications for real-time analytics, and providing temporary data storage while the required data is being transferred to the cloud for long-lasting archiving. Fog nodes positioned in various chosen geographic areas will wirelessly collect the data from the sensor layer through LoRaWan, WiFi, or GPRS technology. The fog layer may include pre-processing, clustering, and clean/relevant data to supplement any missing values in the data it receives. The Air Quality Index is created from the raw data that indicates the concentration of air pollutants, and the hourly standard of the AQI data is then calculated. The dataset employs clustering methods such as K-means to filter the samples. Using supervised learning techniques such as

AdaBoost, K Nearest Neighbor, Support Vector Machines, Decision Tree, Random Forest, Bagging, etc., data on air that are based on AQI ranges established by the EPA are indicated. Predictive modeling employs both regression analysis and machine learning methods.

4.3 Cloud Layer

The cloud receives data from the dispersed Fog nodes for improved data processing and long-term archiving. The chronological data can be categorized, time series analyzed, prognostic models developed, and concealed trends or tendencies identified. When the fog node no longer needs the result, the cloud stores it as part of the suggested structure. The foghead node is situated between the fog and the cloud. If the data is delivered to the cloud after a predefined amount of time and the fog node still desires some result data, the cloud transmits it. Compatibility is one of the many notable characteristics of Fog computing, and it is crucial when considering the diversity of edge nodes at its core. Fog nodes divide certain resources to cooperate with each other, meeting the storage and computing needs of the surrounding fog. In our scenario, it is possible for the fog layer to collaborate through the fog head node server, sharing crucial information with nearby nodes.

5. Experimental Setup

We created a simulation of a scenario where the sensor detects air data and sends the collected data to the fog layer. The fog node analyzes the air data, determines the AQI level of air pollution, and displays the information on a screen (LED) that is connected to the fog layer. A fog head node connects both the fog and the cloud layers. We utilized iFogSim, a toolset for IoT devices, to model the situations. Using iFogSim, we can assess latency and network use. We constructed six fog nodes in our experiment. Three sensors were placed directly in each region to sense the air data. With the help of the Fog head node, we connect with the cloud server. For each location, we created one fog node. We created the sensors by connecting them to the router. To evaluate the outcomes for various scenarios, we expand the quantity of sensors. To analyze the impact on network bandwidth and delay in a fog node, we expanded the number of sensors for a specific instance. We developed an architecture in iFogSim to evaluate the fog state outcomes, as shown in Figure 4. Three sensors were connected to each of the six fog nodes we developed in this architecture. This topology was developed to assess the network utilization and latency in iFogSim. To measure the air quality, we integrated the data-sensing module inside the sensor. For the purpose of processing the data transmitted by the sensors, we designed the data-processing module and integrated it into Fog nodes. The connected smart LED receives information from the fog node regarding the air quality. Contrary to Figure 5, the city develops fog nodes as the number of neighborhoods increases, and these nodes analyze the air quality data.

A specific Fog node's latency rate and network use grow as the number of sensors and LEDs in a Fog node rises. The advantage of using Fog for processing rather than the cloud is that it significantly lessens the computational strain on the cloud. Furthermore, deploying a router to attach the sensors directly to the cloud server causes excessive latency, resulting in increased network bandwidth use. Table 2 displays the cloud server, fog head node, and fog configuration parameters identified during the IoT and fog-enabled scenario simulation, while Table 3 displays the cloud and router configuration. Figure 4 displays the iFogsim cloud-based architecture. In a cloud-based environment, a router connects various sensors and LEDs to the cloud layer for performance analysis. Sensed air data is sent to the cloud and processed by the cloud layer, and information about the air quality in the area is publicized on an LED that is linked to the cloud layer. To evaluate the importance of latency and network utilization, the number of sensors was gradually raised. Table 5 displays the configuration options for the cloud and gateway (router) created for the cloud-based state simulation.

Table 6: Configuration factors of Fog, Cloud and Fog head node

Specifications	Fog	Fog head node	Cloud
Level	2	1	0
Rate per MIPS	0.0	0.0	0.01
RAM(MB)	4000	4000	40000
CPU Length (MIPS)	2800	2800	44800
Uplink (MB)	10000	10000	100
Downlink (MB)	10000	10000	10000

Table 7: Configuration factors of Cloud and Router

Specifications	Router	Cloud
Level	1	0
RAM(MB)	4000	4000
CPU Length (MIPS)	2800	2800
Uplink (MB)	10000	10000
Downlink (MB)	10000	10000

6. Result Analysis

6.1. Assessment of Latency

In situations where excellent real-time performance is required, reduced latency is necessary. Fog provides the benefit of avoiding continual connectivity to the cloud layer and performing calculations at the network to respond quickly to client devices and cut down on latency. The fog devices at the network's edge receive and process the observed data. Each Fog node focuses on a specific location, providing sufficient processing power to swiftly evaluate the data and refresh the information on the screen. Using Eq. 1, the latency is calculated, which comes from [46].

Latency=$\alpha+\mu+\phi$ (1)

Where α is the time required to transmit data to the Fog node for analysis and storage and the triple CPU processing delay needed to capture sensed data are both expressed in. The last consideration is the period of time that passes while the data is processed at the fog node and shown on the LED.

6.2. Assessment of Network Use

Only the cloud resources are utilized when the cloud server's traffic volume increases. An increased amount of traffic on the cloud server leads to more network usage. The network's signal strength decreases as a result of the increased load. A single fog node is assigned to a specific geographic region to process requests for widely dispersed servers coming from that region. In that instance, less traffic is used on the network at a higher pace. Using Eq. 2, the network utilization is calculated from [46].

Network usage = Latency ∂ (2)

where ∂ = tupleNWSize

The simulation is performed using iFogSim for various sensors and routers in the proposed work. The result is obtained for different combinations of the sensors in the simulation environment, and the corresponding values are represented in Table 8.

Table 8: Comparison of Latency between cloud and Fog

No of Air Quality Sensors	Fog Latency (MS)	Cloud Latency (MS)	Fog Network Usage (KB)	Cloud Network Usage (KB)
3	65.75	214.79	5626.8	773986.6
6	259.22	480.08	216180	1107180.6
9	259.96	680.54	324270	1150800
12	260.75	780.77	432164.3	1194418.8
15	261.71	840.91	539703.5	1238036.7
18	262.75	881.00	647236.7	1281654.3
21	303.23	918.15	720244.7	1319853.3
24	402.32	956.41	724208.3	1347815.1
27	479.33	982.66	728171.9	1366464.9
30	540.89	1001.46	732135.5	1380470.7

7. Discussion

This section contrasts the results of the suggested fog-based architecture with a cloud-based deployment in terms of both latency and network use. The results of the testing demonstrate that the fog-based solution uses less bandwidth and has lower latency than the cloud-based version. Table 8 displays the network usage and latency findings for the Fog environment, as well as the cloud-based deployment results.

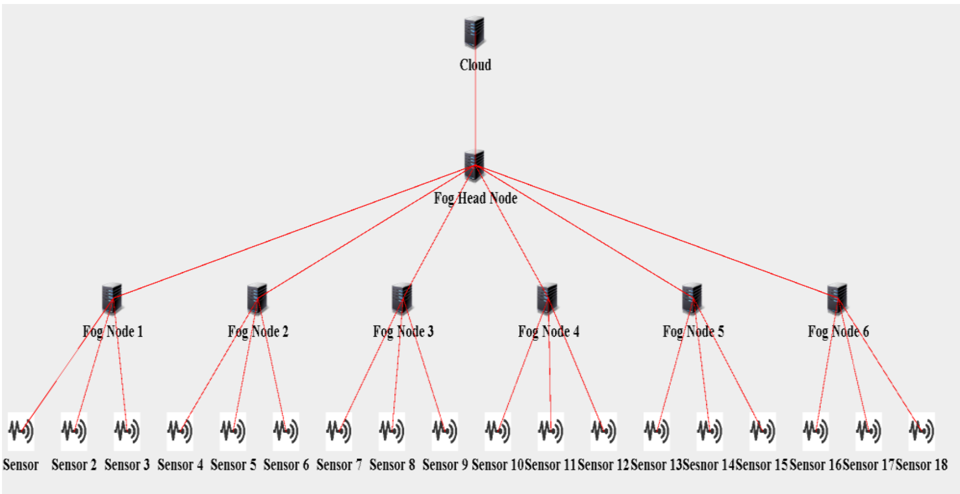

Figure 8: Simulator iFogSim topology of 18 sensors, 6 Fog nodes and associated to the cloud via the Fog head node

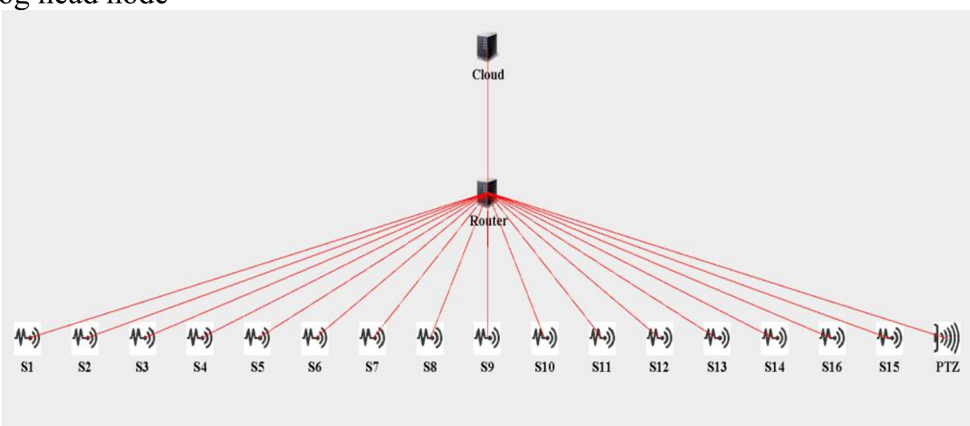

Figure 9: iFogSim topology of 15 sensors linked with the cloud server via router

The architecture of our suggested air quality monitoring equipment based on Fog, as illustrated in Figure 2, is successful, according to experimental data. Table 3 illustrates the development of various fog and cloud-based setup scenarios, which enabled the connection of varying numbers of sensors to fog nodes and cloud servers. We developed six fog nodes to evaluate the results based on the fog. Six fog nodes and 18 sensors are installed for scenario 1. Each fog node is connected to one of the three sensors. Each scenario sees an increase in the number of sensors in addition to the fog nodes and cloud server. In the cloud state, we used a router to link the sensors to the cloud.

The testing results for the two assessment criteria, namely latency and network bandwidth, when combined with the Fog paradigm and cloud-based achievement demonstrate the effectiveness of the proposed Fog-based framework for air quality monitoring. By employing the fog-based framework to monitor air quality, we swiftly acquired information about the extent of air pollution. Furthermore, the results reinforce our comprehension of fog's potential in the IoT scenario, as prompt response times are highly desirable. In conclusion, the Fog-based architecture, with its low latency and minimal network utilization, is better suited for applications that require rapid response in less time.

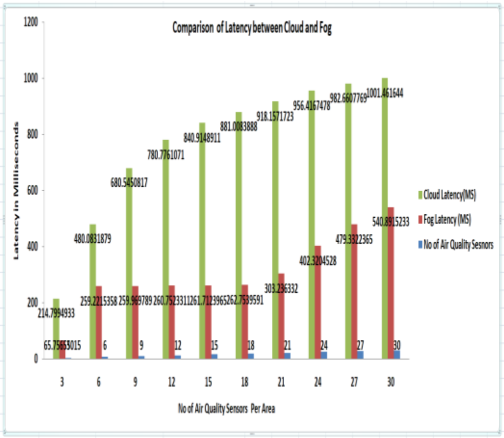

Figure. 10: Graphical representation of Latency of usages between Cloud and Fog network
Fog network

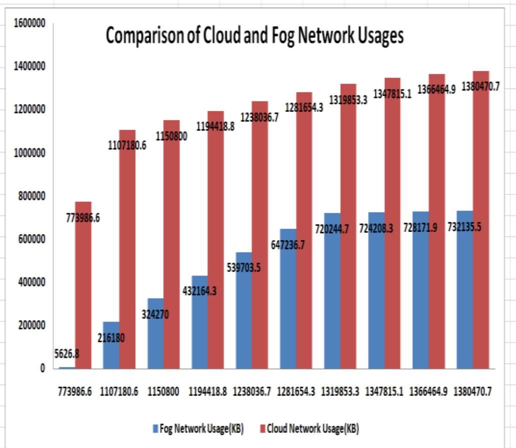

Figure. 11: Graphical representation between Cloud and

8. Conclusion and Future Work

Fog technology uses cloud computing to handle the massive amounts of IoT data that arrive on a regular basis. It helps with difficulties like data pace, diversity, and volume explosions. It also gives a better understanding and awareness of incidents by removing a cognitive roundtrip to the cloud. The fog paradigm is an addition to the cloud, not a replacement. Fog computing, a cloud-based solution, manages the vast volumes of data gathered daily from IoT devices and handles it close to its origin, addressing the challenges of increasing data amount, diversity, and rapidity. The fog paradigm makes sense, and it increases reactivity to situations by preventing transport to the cloud for processing. By redirecting terabytes of network congestion away from the network, it improves exclusive capacity expansion and also aids in the security of IoT data. Fog computing enables companies to deliver real-time information, resulting in increased enterprise flexibility, levels of service, and safety. We aim for the Fog to serve as a unified platform that not only facilitates this new era of service development but also enables the implementation of innovative apps.

In order to do this, we put out a fog-based air quality monitoring framework that employs computer vision techniques to quickly and accurately identify an AQI. The experimental findings suggested that, in addition to using much fewer network services than the cloud, fog-based architecture significantly reduces latency. As a result, we plan to investigate the load balancing issues in Fog nodes in the future and devise a feasible solution. To find a practical solution, we aim to investigate the issue of work offloading and optimize the use of Fog computing resources in Fog nodes going forward.

9. Conflict of interest

The authors declare that they have no conflicts of interest.

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